The Discovery of Calcite Intrinsic Wettability by the First-Ever Optical Illumination Inside Dark Fluid using IRIDW Apparatus

Omar Alfarisi, Aikifa Raza, TieJun Zhang

Abstract
Wettability is one of the critical physical-chemical properties controlling multiphase flow in porous media. Therefore, it is vital to identify the wettability for each rock type when building 3D geological models for predicting the fluid flow behavior using a numerical simulator. Wettability-unique relative permeability curves are part of each flow simulator's rock type for proper simulation predictions. The reference approach for wettability determination is contact angle measurement. The literature recoded the wettability of contact angle measurement inside transparent fluid like water and decane. However, we need to visualize and measure the water-rock contact angle inside dark fluid like the hydrocarbon. We propose visualizing and measuring the wettability contact angle for rock-water inside dark hydrocarbon fluid. We use the Illumination through Rock Inside Dark fluid for Wettability measurement (IRIDW) apparatus.

Introduction
Each 3D geological grid block [1-3] requires a rock type [4-8] with physical and chemical properties [9, 10] like lithology [11, 12], porosity, permeability, capillary pressure [13-30], fluid saturation[31-39], relative permeability [40], and wettability[41, 42]. Wettability is one of the main controlling attributes of fluid flow in porous media. However, most of the used wettability values are assumption-dependent rather than in-situ intrinsic rock values. Method unavailability for measuring surface wettability inside dark hydrocarbon fluid is one reason for Figure 1. Carbonate rock holds heterogeneous morphology [43], making measuring the rock surface wettability complex. Therefore, to solve the heterogeneous carbonate wettability, understanding the intrinsic wettability of calcite is vital.
Researchers worked on several methods for quantifying wettability in water and hydrocarbon-bearing formations using experimentation and numerical simulation. Experiment-based measurements include static and dynamic processes. The static process visually measures Contact Angle (CA) between a fluid and solid emersed in a second fluid. The CA method is the reference method for all others. Dynamic processes deliver a wettability index using flooding cycles containing alternating forced and spontaneous flow. On the other hand, the simulation methods include mainly Lattice Boltzmann flow simulation [41] and quantum simulation [44].

Inside dark hydrocarbon, engineers and scientists couldn't use CA to measure wettability because of invisibility. Hence, all rock typing approaches lack the related physical and chemical properties at the true wettability. Therefore, engineers assume several wettability conditions for determining the permeability, capillary pressure, and relative permeability (i.e., water wet, mixed wet, or hydrocarbon wet). In contrast, the proper determination would consider the in-situ wettability for each rock at the actual depth below sea level. However, the wettability in hydrocarbon-bearing zones is unavailable due to the contact angle invisibility. We propose wettability determination using the Illumination through Rock Inside Dark fluid for Wettability measurement (IRIDW).

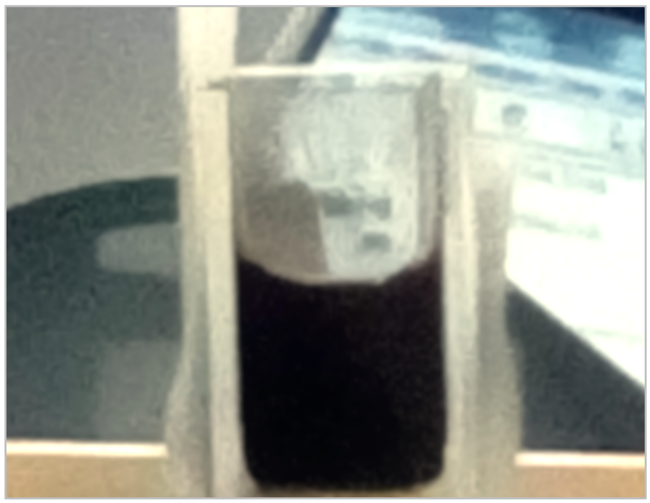

Figure 1. Dark fluid (hydrocarbon) has a calcite rock and water droplet inside; however, everything is invisible.

Method

The IRIDW apparatus consists of two light sources, a metal stage with a hole, a glass beaker, and a camera, Figure 2. The first light source forms 180° with the camera, representing a standard CA measurement setup. However, the second light source under the metal stage, which creates 90° with the camera, is one of the novel additions to the standard apparatus. In Figure 1, the first light source illuminates the glass beaker alone, without using the second source, where all the beaker emersed calcite rock and water droplet contents are invisible. We propose creating a path for light photons to reach the calcite rock and the water droplet to illuminate them in a dark hydrocarbon fluid. As shown in Figure 2, we added a second light source below the metal stand. We have a hole in that metal stand, enabling the light photons to pass through the hole and reach the glass beaker containing the calcite rock, water droplet, and dark hydrocarbon fluid. The light photons continue their path inside the calcite rock to illuminate it and continue further to illuminate the water droplet. The camera position in Figure 2 is the same place as Figure 1.

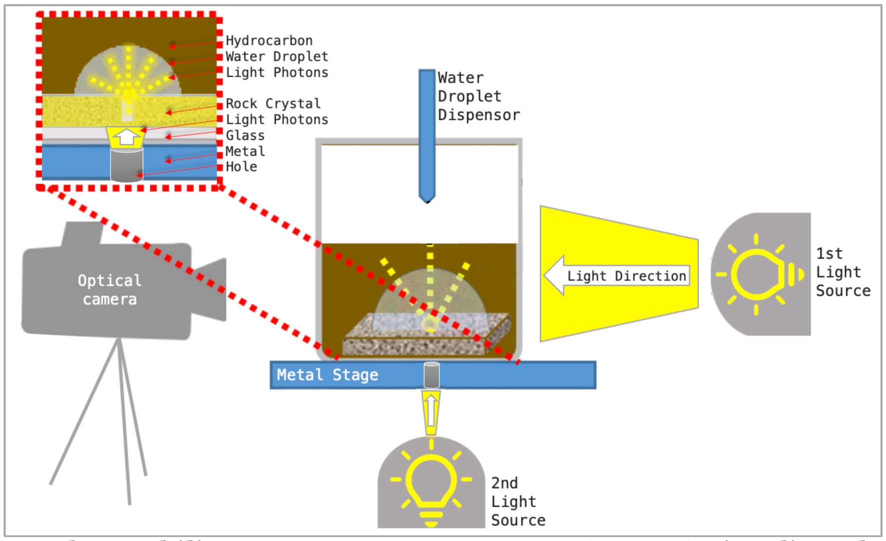

Figure 2. Novel wettability measurement apparatus (IRIDW) visualizes the emersed calcite and water droplet inside dark hydrocarbon.

Result and Discussion

Once we apply the novel setup of IRIDW shown in Figure 2, we can see the contact angle of a water droplet on calcite rock for the first time inside a dark hydrocarbon fluid, Figure 3. This visualization marks the discovery of calcite surface wettability inside hydrocarbon as the first reference for further experimentation using IRIDW.

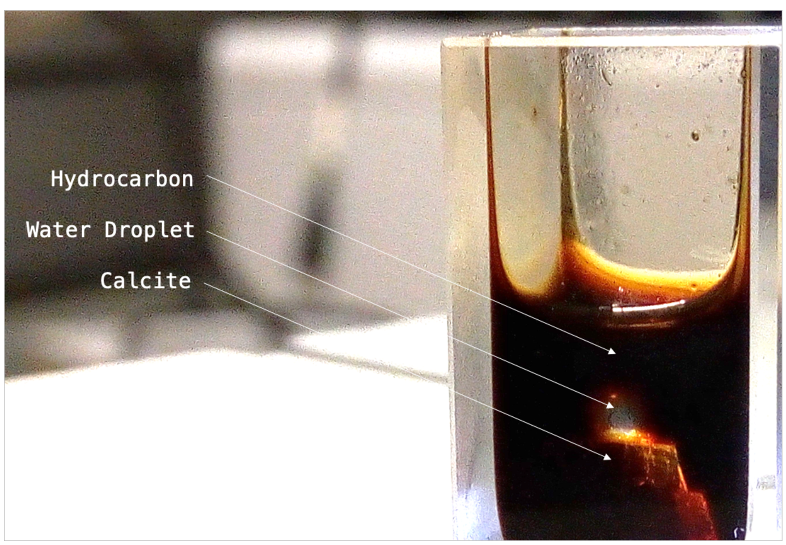

Figure 3. The first record of an illuminated water droplet on top of calcite rock inside dark hydrocarbon fluid, using IRIDW.

For a visual comparison of the dark hydrocarbon-bearing glass beaker in two different measuring apparatus, we display Figure 4. The left-side image of Figure 4 shows the pictured dark hydrocarbon-bearing glass beaker without the IRIDW apparatus. In contrast, we record the right-side image of Figure 4 with IRIDW to see what is inside the dark hydrocarbon-bearing glass beaker.

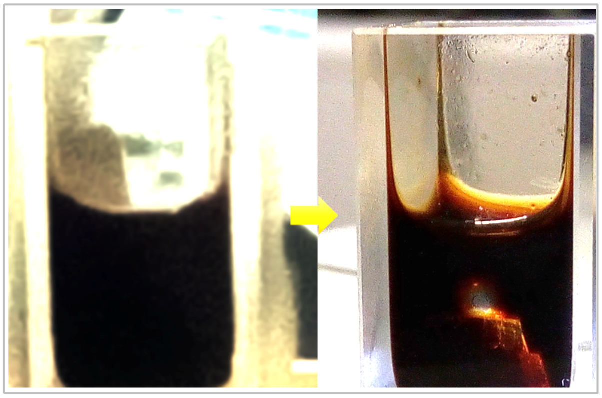

Figure 4. Comparing the glass beaker image (left) without using IRIDW and the appearance of the same beaker after using IRIDW setup (right), showing the first-ever image of a water droplet on top of calcite rock inside dark hydrocarbon fluid.

When we magnify Figure 3, the image is unclear, as shown in Figure 5. However, we need a more precise visualization to measure the contact angle between the calcite surface and the water droplet. Therefore, we enhance the camera's focusing, as shown in figure 6. The left side of the image is the IRIDW camera. The right-side image is the illuminated calcite and the water droplet inside the dark hydrocarbon with better visibility to enable accurate contact angle measurement.

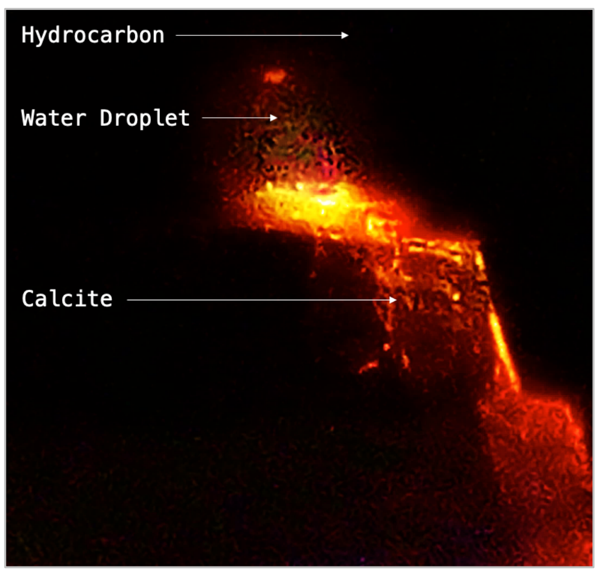

Figure 5. The first image, digitally magnified, of a water droplet on top of calcite rock, where both are inside dark hydrocarbon fluid.

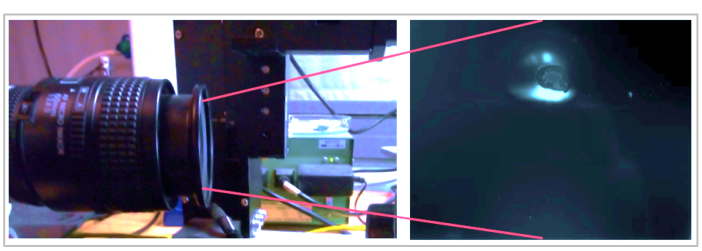

Figure 6. The camera (left) recorded enhanced visibility of a water droplet on top of calcite rock, where both are inside dark hydrocarbon fluid.

We further enhance the visibility by making the calcite and the water droplet closer to one of the glass beakers' sides. We record another image inside the dark hydrocarbon fluid, as shown in Figure 7. We applied digital image filtering to have a more precise picture to enhance further the visibility for measuring the contact angle, as shown in Figure 8.

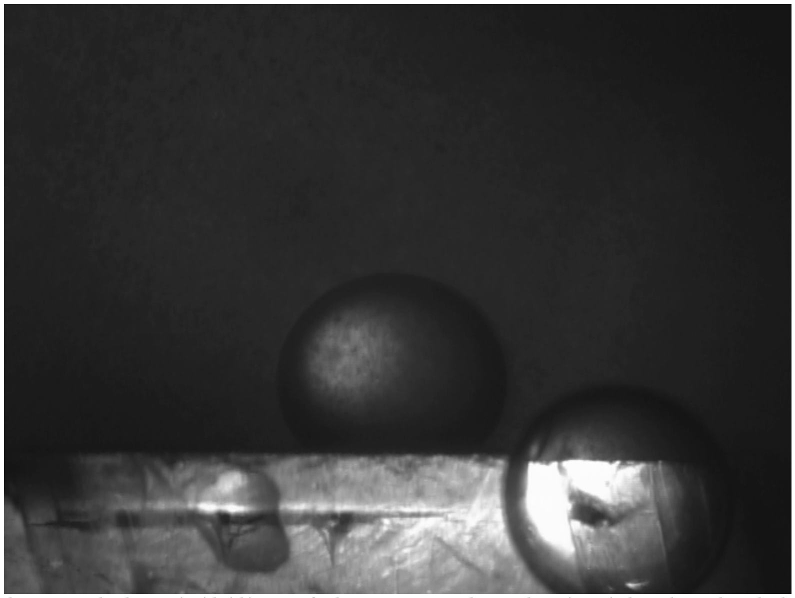

Figure 7. Enhanced the visibility of the water droplet inside the dark hydrocarbon by bringing the calcite rock closer to the side edge of the glass beaker.

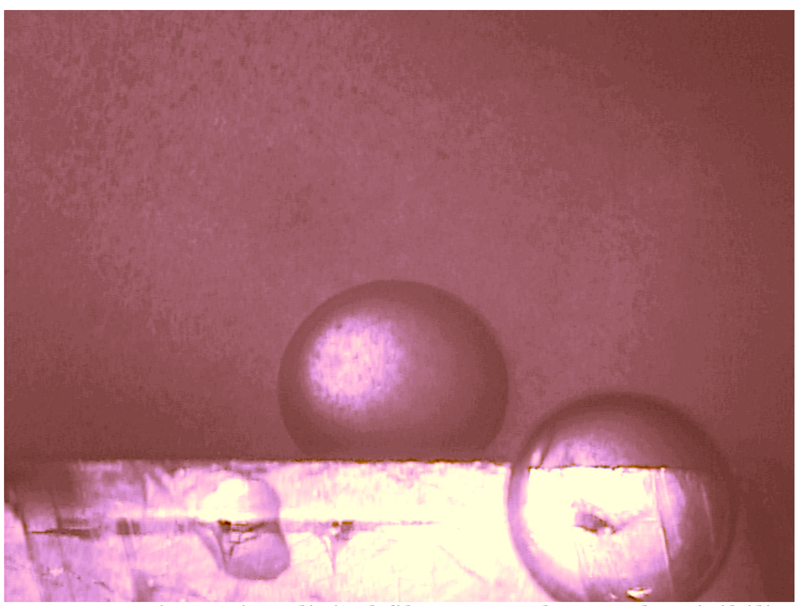

Figure 8. Image processing using digital filters to enhance the visibility of the water droplet on top of calcite inside a dark hydrocarbon.

We measure the contact angle between the calcite rock surface and the water droplet, showing 142°, Figure 9. Therefore, we conclude the wettability of calcite as hydrocarbon wet because the water droplet is more than 90°. At the same time, in other literature, we see that calcite shows a water-wet behavior [44, 45]. Our work confirms that calcite has a non-preferential affinity to water or hydrocarbon; instead, calcite shows an association with the fluid that first touched the surface. We infer that unless additional mechanical forces exist (e.g., extra pressure) or electrochemical alterations [46], then the wettability of calcite holds an affinity to the first fluid.

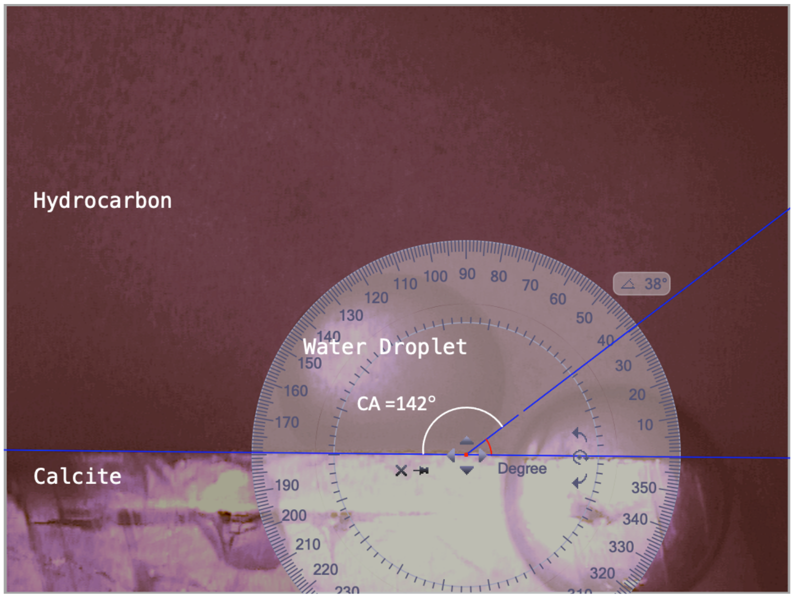

Figure 9. The contact angle (CA) measurement of a water droplet and calcite surface inside dark hydrocarbon fluid.

Conclusions

- For the first time in human history, the contact angle measurement for rock surface wettability inside dark hydrocarbon fluid is measurable using the IRIDW apparatus.
- To make the items inside dark hydrocarbon fluid visible, IRIDW introduces a second light source and provides a path for the light photons to illuminate the calcite rock crystal and the water droplet on top.
- Enhanced visibility inside dark hydrocarbon fluid is evident when the rock and water droplet is near the beaker side facing the camera.
- The calcite intrinsic wettability has no preferential to a fluid. Instead, the first fluid that touches the calcite surface governs the wettability of calcite.

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Remarks

- This paper version is a preprint for submission at the engrXiv.org library.
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