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Using the Volume of Fluid Method, Gas and Water Two-Phase Flow in Rough-Walled Fractures is simulated at the Pore Scale

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Introduction

Understanding the gas production characteristics of naturally fractured formations depends on the pore-scale behavior of gas and water in rough-walled hydrophilic fractures. The volume of fluid (VOF) method is used to conduct a systematic analysis of the gas and water flow characteristics in both single-fracture and Y-shaped junction fracture models in this paper. The geometry, phase distribution and saturation of gas bubbles and slugs were all influenced by the gas/water rate ratio, according to numerical simulations. The gas/water ratio has a greater impact than the fracture roughness and tortuosity, while the total fluid rate has a negligible impact. The phase distribution and referential pathways in Y-shaped junction models are mostly controlled by the channel aperture ratio alone, so the impact of the intersecting angle and fluid flow rate can be ignored.

Description

Coal, shale and carbonate are examples of naturally fractured gas formations that contribute significantly to global energy supplies. Because discrete fractures contain either naturally occurring water or injected water-based fracturing fluids, gas and water two-phase flows are common. It is common knowledge that the interactions of gas and water at the pore scale have a significant impact on the production characteristics as well as the fluids spatial distribution and flow capacities.

Laboratory microfluidics and numerical simulation have been proposed as two types of investigation tools for studying the pore-scale interactions between water and gas. Multi-phase flows can be directly observed at micron-scale geometries thanks to microfluidics.

The gas and water flow patterns in a single fracture or complex fracture network have been the subject of numerous experiments. The interactions between water and gas at the pore scale were directly observed in previous experimental work. However, because the majority of these earlier works utilized microchip models with particular wall roughness, they did not provide insights into how the flow pattern is affected by the fracture roughness. Due to the limited resolution of images, the microfluidic method also has difficulty with interpretation accuracy. The picture goal of current business magnifying lens is for the most part on the size of micrometers. However, the recorded images are unable to accurately depict the fluid distribution on the rough surface if the wall roughness is less than a few nanometers. In addition, microfluidic experiments typically come at a high cost and necessitate the use of specialized microfluidic chips, microscopes and high-speed digital cameras. Numerical simulations, in comparison to the microfluidic experiment, are typically less expensive, more adaptable and offer quick predictions for a wide range of flow conditions.

Particle network modeling (PNM) and computational fluid dynamics (CFD) are two of the most widely used approaches to simulating multiphase flow at the mesoscale (or pore scale). Instead of using the actual flow path geometry, the PNM runs simulations on conceptual models with simplified pores and throats geometries. As a result, the reconstructed discrete physical pore–throat model's accuracy plays a significant role in determining the PNM's accuracy. For geometric models with high irregularity, it is acknowledged that the PNM is unable to make accurate predictions of fluid–solid interactions and flow characteristics. Besides, the PNM requires a predefinition of specific components, for example, the snap-off and pore-filling for displaying multiphase streams, which definitely gets extra mistakes. The CFD method is regarded as being more accurate than the PNM because it is able to directly simulate fluid flows on genuine physical models with intricate geometries. Besides, the CFD strategy is fit for displaying a more mind boggling multiphase stream that includes blend wettability, heat move and strong molecule stream. Among the different CFD techniques, the LBM and VOF are the most usually utilized for demonstrating two-deliberately ease streams in permeable media at the mesoscale.

The LBM strategy is better than the VOF technique as far as union steadiness and preservation precision for recreating incompressible liquid stream. However, when simulating multiphase flow with a high density and viscosity ratio (such as gas/water or gas/oil two-phase flow), conventional LBM is associated with the problem of numerical instability. Additionally, when compressible fluids are taken into account, the LBM method encounters inherent difficulties when dealing with compressibility issues. Mass conservation is an inherent benefit of the VOF method and it doesn't need a complicated phase interface tracking algorithm to calculate two-phase flow in complex geometric shapes. As a result, when it comes to simulating multiphase flow in pathways with intricate geometries using compressible fluids and a high density/viscosity ratio, the VOF method is more mature and reliable than the LBM. Combining the volume fraction model with the Navier–Stokes equations and then employing numerical computation methods to solve the discretized equations is the fundamental tenet of VOF.

Although it has been demonstrated that the VOF method is capable of simulating compressible fluid flows in channels in meso- and macroscale sand packs or pipelines, very little research has reported the use of the VOF method to investigate the interactions between gas and water in pore-scale fracture networks. However, this is something that is still a work in progress. The only paper that, to the best of the authors knowledge, reported gas and water flow simulations in microscale fractures and demonstrated the precision of CFD simulations of gas and water flow patterns in Y-junction models. However, all of the simulations used smooth fractures, which are not the same as rough fractures in reality. Additionally, the effects of gas compressibility are ignored by the utilized model. Two-phase gas and water flows were simulated in rough-walled single-fracture and Y-shaped junction models using the compressible VOF technique in this study. New insights will be shared as a result of the investigation of the interactions that take place between the two-phase fluids in various fracture geometries.

The VOF method was used to run numerical simulations of gas and water flows in Y-shaped junction models with rough walls and single fractures, taking into account a variety of factors. The following summarizes the main conclusions drawn from the simulation results: The gas/water ratio is the primary factor that determines gas bubble geometries, phase distribution

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and saturation in single-fracture models. The impacts of unpleasantness and convolution on the state of gas air pockets and leftover water immersion are observable however fundamentally not exactly the impact of the gas/water proportion. In single-fracture models, the gas and water flow pattern is not significantly affected by total fluid rate.

When the apertures of the adjacent downstream channels are not the same, gas preferentially flows through larger paths in the Y-shaped junction model. In Y-shaped junctions, the characteristics of the phase distribution are largely unaffected by the intersecting angle and fluid flow rate [1-5].

Conclusion

In this study, the fracture wettability was assumed to be hydrophilic, so the findings may not apply to mix-wetting or hydrophobic fractures. As a result, the impact of wettability on the two-phase flow characteristics of rough-walled fractures may warrant additional research. It should also be mentioned that the conceptual single- and Y-junction fracture models are the focus of this paper. The fracture network's spatial distribution and connectivity may be more complicated in genuine naturally fractured reservoirs. As a result, it is anticipated that simulations of gas and water flow through genuine fracture networks will reveal the two-phase interaction characteristics under the influence of various factors like flow rates and patterns of fracture networks.

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