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A permeability determination method for irregular rocks based on numerical Transient Pressure Pulse Decay (TPPD) testing

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ABSTRACT

Permeability is a key parameter characterizing the flow capacity within porous reservoirs. The Transient Pressure Pulse Decay (TPPD) method is a widely employed technique for permeability characterization; its reliance on the formula necessitates regularly shaped samples. However, samples often experience fragmentation during coring, making it difficult to obtain regular specimens. This study proposes an innovative method combining a modified TPPD experiment for irregular samples with a mathematical model describing the entire testing process, where permeability is determined through inverse problem optimization. Initially, the study conducts tests on regular samples. The results demonstrate strong agreement between the numerically simulated and experimentally measured pressure differential data, with fitting accuracy (R^2) beyond 0.9776. Those confirm that the proposed model accurately captures the physical process of the TPPD experiment. The best inverted permeability of 0.148 mD (95 % CI: [0.142, 0.156] mD) closely matches the formula-derived value of 0.143 mD, further validating the model's accuracy. Subsequently, irregular specimens are prepared from the original regular samples and tested by the new method. The results show excellent fitting precision, with R^2 consistently exceeding 0.9659, proving that the model can also precisely replicate the testing process for irregular samples. However, the permeability differs significantly from that of the original sample, which is attributed to imperfections in the preparation process. The new method has removed the limitation of laboratory permeability measurement on the shape of rocks, facilitating the research on the flow in unconventional reservoirs.

1. Introduction

With the global energy transition, subsurface development demonstrates significant potential across multiple directions. For instance, unconventional hydrocarbon resources[1] (e.g., shale gas, coalbed methane, and tight oil) have attracted considerable attention, with their extraction relying on reservoir stimulation methods including hydraulic fracturing.[2] Carbon capture and storage technologies inject industrially emitted CO_2 into deep geological formations,[3,4] enabling carbon management through sequestration. Meanwhile, emerging deep subsurface energy storage technologies, including compressed gas storage[5,6] and thermal storage,[7,8] utilize underground spaces as buffers for energy distribution. These technologies involve transforming the physicochemical conditions within reservoirs to achieve energy extraction and storage. The effectiveness of these technologies primarily depends on the accurate characterization of permeability. As a critical parameter governing fluid flow in porous media, permeability determines development strategies for unconventional hydrocarbon reservoirs,[9] the long-term stability of CO_2 storage formations,[10] and the charge-discharge efficiency of deep storage systems.[11–13]

To precisely measure permeability and adapt diverse engineering applications, researchers have pursued investigations from multiple

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