The Latest Developments of Laboratory NMR Techniques in Unconventional Shale Characterization

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Abstract:

The complexity of the microstructure and fluids in unconventional reservoirs presents a significant challenge to the traditional approaches to the evaluation of geological formations and petrophysical properties due to the low porosity, ultralow permeability, complex lithology, and fluid composition. Nuclear magnetic resonance (NMR) techniques have been playing major roles in unconventional shale characterization in the last decades as NMR can provide critical information about the reservoirs for quantifying their petrophysical parameters and fluid properties and estimating productivity. Laboratory higher frequency (HF), e.g., 23-MHz NMR techniques, especially two-dimensional (2D) T1-T2 mapping, and their applications have been essential for the noninvasive characterization of tight rock samples for identifying kerogen, bitumen, heavy or light hydrocarbons, and bound or capillary water. The traditional T2 cutoffs need new definitions to reflect the inferences from water and hydrocarbons separately. The legendary crushed rock analysis method, as applied to unconventional formations, has shown great success in evaluating total porosity and water saturation but suffers from inconsistency in results due to desiccation and solvent effects. The industry has witnessed significant development of HF NMR techniques that couple advances in petrophysics, petroleum engineering, and geochemistry with a broad range of applications. This article will summarize key advances in laboratory NMR applications in unconventional shale characterization, including monitoring processes of liquids equilibrium, desiccation, and imbibition in fresh shale samples, determination of activation energy of hydrocarbons in shales, monitoring changes in a shale sample during liquid flooding experiment, and direct measurements on kerogen. Future NMR applications, such as in EOR, gas condensation, and saturation profile, will be discussed. In this article, we will review the following techniques: laboratory NMR, especially 23 MHz, techniques for unconventional shale sample measurements, 2D NMR T1-T2 mapping with an inter-echo spacing time of 0.7 ms at various sample temperatures, and early-time NMR signals acquired using the solid-echo pulse sequence together with pyrolysis results in kerogen studies. We will review the importance of the inter-echo spacing time in shale NMR experiments, give examples of monitoring liquid redistribution and desiccation in fresh shale samples, compare the results from NMR, Dean-Stark, and pyrolysis, examine the multidiscipline approaches as better tools to solve petrophysical problems. Examples include kerogen study using the solid-type NMR measurement combined with geochemical pyrolysis and NMR combined with capillary pressure. There has been significant advancement of NMR techniques in unconventional shale evaluation over the last decade. It is time for us to summarize such technological advances and draw conclusions to help us in planning unconventional core analysis programs.

Bio:

Z. Harry Xie is the NMR Senior Advisor at Core Laboratories. He received his PhD in Physics from the University of Kent at Canterbury, UK, in 1994 and worked as a research fellow for both the University of Surrey and the University of Kent. Dr. Xie has spent 15 years working in the analytical instrument industry to develop and support laboratory time-domain NMR products at Resonance Instruments Ltd., UK, and at Bruker, respectively. Dr. Xie has been focusing on developing new NMR techniques and applications, permeability models, and petrophysical data processing techniques for unconventional tight rocks such as oil and gas shales since he joined Core Lab in November 2012.

Dr. Xie has been an active contributor to the SPWLA. He successfully organized and co-chaired the 2016 NMR Topical Conference and was one of the key players in setting up the NMR SIG (Special Interest Group) of SPWLA. He served as the president, past-president of NMR-SIG. He was the 2021-2023 VP of Information Technology, and is 2023-2024 VP Technology-Elect of SPWLA.