Advances in Pore Structure Characterization: A Machine Learning Approach Combining NMR and CT Data for Physically Reliable MICP Estimations

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Abstract
Objectives/Scope: This study aims to develop a machine learning model that combines Nuclear Magnetic Resonance, X-ray Computer Tomography, and conventional core analysis data for Mercury Injection Capillary Pressure (MICP) predictions, which are crucial for reservoir rock characterization and also plays a major role in enhanced oil recovery. The objective is to obtain capillary pressure curves without running MICP due to the fact that it is expensive and environmentally detrimental especially due to sample disposal.

Methods, Procedures, Process: The proposed multimodal ML model combines time-series feature engineering techniques applied to NMR data and embeddings generated from CT sequence image data using neural networks (NN), alongside CCA data. This diverse dataset includes various rock types and pore structures, enhancing the model's applicability and robustness. The model evaluates drainage capillary pressure trends with pore entry size, pore throat size distribution, utilizing NMR, CCA and CT image data obtained from several scanned slices on each plug. The model is compared with traditional methods and alternative ML models using different feature subsets to demonstrate its superiority in MICP prediction accuracy and reliability.

Results, Observations, Conclusions: The integration of NMR, CT, and tabular data led to significant improvements in MICP prediction accuracy and physical reliability. The high-resolution, three-dimensional pore structure information provided by these imaging techniques captured the complex relationship between pore geometry and capillary pressure. The model can help in predicting capillary pressure behavior for non-tested MICP samples, provide a screening QC tool for those being tested, and be applied for both conventional or unconventional reservoirs. The end user will be able to generate a preliminary MICP view for plugs under study, expediting the selection and picking of intervals to perform saturation height function and reserve estimation. Therefore, an in-depth analysis of feature importance highlights the crucial role of specific NMR and CT features for the predictive performance of the model, suggesting further optimization opportunities and more efficient data acquisition strategies.

Novel/Additive Information: This paper introduces a novel ML model that combines NMR, CT, and tabular data for improved MICP predictions. The approach enhances pore structure analysis and fluid flow property predictions in various fields, contributing to the state of knowledge in the petroleum industry and benefiting reservoir characterization studies. In addition, the model reduces the number of samples required for MICP tests, enabling prediction of capillary pressure curves for all samples that have CT and CCA data.