Annual Report for PRF# 59089 DNI - 9

Project Title: Statistical Deep Learning-based Model (SDLM) for Direct, Fast, and Accurate Pore-Scale Modeling of Multiphase Flow in Porous Media

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Progress of the Research

This annual report presents the ongoing work for the development of statistical neural network-based models reservoir characterization and pore-scale simulation of flow on micro-CT images. The proposed model simulates multiphase flow condition directly on images of complex carbonate to examine fundamental rock and fluid physics by including wettability, pore size distribution, and connectivity on the resulting relative permeability and capillary pressure curves. Over the last year, our efforts on this grant have focused on the application of AI in multiphase flow through porous media to predicting capillary pressure and relative permeability curves. Multiple artificial Neural Networks (ANN) are trained to simulate two-phase capillary pressure and relative permeability data in bundles of capillary tubes with non-uniform arbitrary wettability conditions and cross-sectional shapes of different irregular convex polygons. All polygons with variable number of corners are randomly generated for a given range of inscribed radii, shape, and elongation factors. To generate the data for the training of ANNs, the minimization of Helmholtz free energy and Mayer-Stowe-Princen (MS-P) method are combined to find thermodynamically consistent threshold capillary pressures for two-phase flow. These capillary pressures are then used to determine the sequence of displacements in different capillary tubes. We calculate saturation and phase conductance at each quasi-steady-state condition where no more displacements can be done for a given capillary pressure. The generated two-phase capillary pressure and relative permeability curves are then used for the training of ANNs. We test different designs of ANNs to find the optimal workflow for the training and predicting of petrophysical properties related to multiphase flow. In this research, we present the results of two different neural network structures (Figure 1). In the first structure, we use ANN to predict threshold capillary pressures of different capillary tubes during a drainage process (i.e., oil-to-water displacements). In the second structure (Figure 2 and Figure 3), we predict capillary pressure and relative permeability curves for an arbitrary bundle of capillary tubes. The first structure of ANNs simulates a fixed property for a given capillary tube, whereas the second structure simulates time-series data format (i.e., for a given bundle of capillary tubes calculated properties vary with saturation). To do so, we have generated multi-phase flow properties for two large datasets consisting of 40,000 and 60,000 capillary tubes each. High-quality training datasets are critical in the training of high-fidelity ANN models. These models can then learn the impact of a wide variety of pore geometries (i.e., shape factors and elongations).

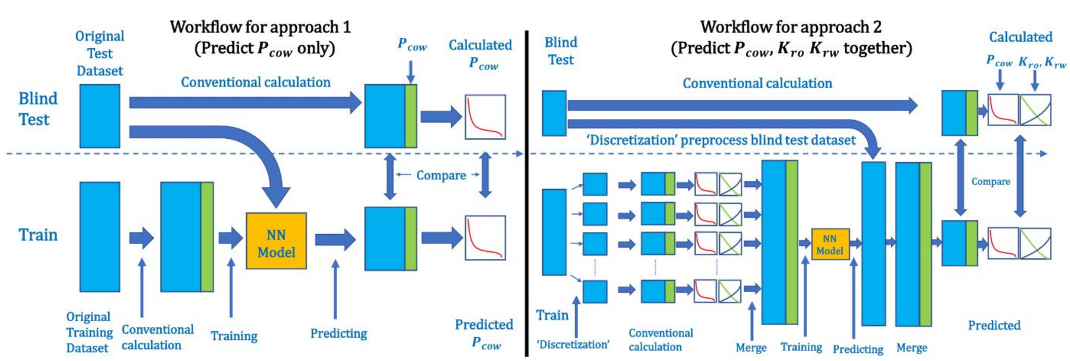

Figure 1: The workflow of two Neural Network training and predicting logics: (1) The approach 1 is simpler with only one output which is P_{cow}, the ANN will be trained based on the area (A), perimeter (P), number of edges/corners (n), largest inscribed radius (R_{in}), shape factor (g_{cc}), elongation factor (g_{el}). (2) Approach 2 includes water-saturated cross-section area S_w_area, oil flow rate q_o and water flow rate q_w in addition to P_{cow} as the output parameters. They will serve as the intermediate variables for constructing the relative permeability curves.

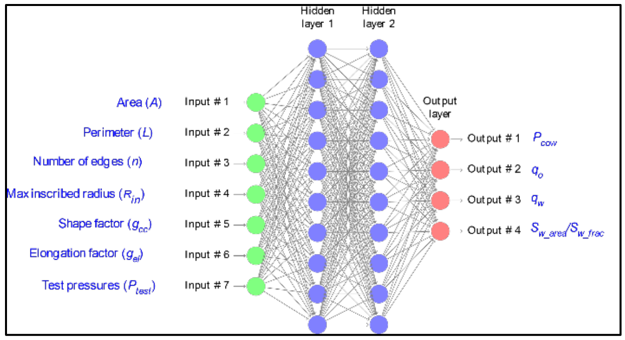

Figure 2: The example network structure for approach 2

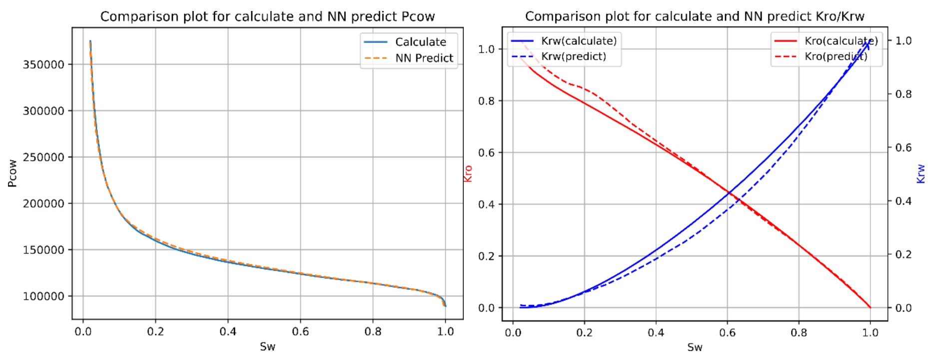

Figure 3: P_{cow} comparison plot for test data with shape factor from 0 to 0.04 for training dataset 2 by approach 2 (S_w_frac in output) b. K_{ro}/K_{rw} comparison plot for test data with shape factor from 0 to 0.04 for training dataset 2 by approach 2 (S_w_frac in output)

Our study shows that AI can speed up our calculations by a factor of 10 compare to the conventional approaches. when the number of capillary tubes reached 100,000 and total tube, test pressure combination is reached 20,000,000. Note that the model is for a bundle of capillary tubes. The realistic 3D pore-throats model with complex geometries and connectivity would be more computationally expensive.

For the next progress report, we will develop a pore-scale network model for the simulation of displacement sequences during drainage and imbibition in the presence of micro-pore networks. To do so, we will construct 'macro' networks on 2D rectangular lattices which are later altered to include micro-pores. A comprehensive set of sensitivity analyses will be performed to assess the impact of various parameters including the tortuosity, geometry, and location of the micro-porosity (i.e., parallel or in series, continuous or non-continuous). Also, 3D networks for two different rock samples will be used to investigate the effect of pore size distributions (PSD) on the electrical resistivity curves. This work will help to examine the use of Archie's equation for field applications, specifically, for evaluating formations with wide PSDs like carbonate reservoirs.

Publication from This Grant:

The following journal paper has been published from this research and the citation of this published article is submitted through the http://prf.confex.com/prf/2019/cfp.cgi.

1. S. Liu, A Kalantari-Dahaghi*, A. Zolfaghari, S. Negahban "Application of Neural Networks in Multiphase Flow through Porous Media: Predicting Capillary Pressure and Relative Permeability Curves", Journal of Petroleum Science and Engineering, Vol. 180, Pages 445-455, May 2019.

Impact of the Research on My Career

Receiving this ACS-PRF New Directions grant allowed me to pursue a new direction in the area of pore-scale modeling research that I would not have been able to pursue otherwise.

Advancing Scientific Education and Student Training

To date, this project has contributed to the scientific education and laboratory training of multiple graduate students, and a partial finding of a Post Doc to conduct MicroCT laboratory measurements.