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Direct observation of phase change in sub-10 nm porous media

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Phase change at the nanoscale is critical to many industrial applications including rapidly emerging unconventional oil and gas production from nanoporous shale reservoirs. The thermodynamic behaviour of hydrocarbons confined to these nanopores is expected to deviate significantly from bulk properties and there is little experimental data to validate theories. This research aims to visually observe the evaporation of hydrocarbons in a nanofluidic chip that accurately represents the geometric dimensions and the pressure/temperature conditions observed in shale. The chip consists of a nanoporous network of two-dimensional (2D) nano pores with dimensions down to 8 nm. Using an experimental procedure that mimics pressure drawdown during shale oil/gas production, our results show that evaporation of pure propane takes place at pressures lower than predictions from the Kelvin equation (maximum deviation of 11%). We probe evaporation dynamics as a function of superheat and find that vapor transport resistance dominates evaporation rate. For the transport resistance in the sub-10 nm nanoporous media, the contributions of the Knudsen flow and the viscous flow are found to be approximately equivalent. We also observe a phenomenon in sub-10 nm confinement wherein lower initial liquid saturation pressures trigger discontinuous evaporation resulting in faster evaporation rates. Additionally, we also extend this work to study evaporation and cavitation dynamics in nanofluidic devices with (a) mixture of pore sizes coupled with (b) mixture of hydrocarbons. Collectively, the results presented will aid in increasing the efficiency of shale production and will inform modelling and simulation of shale gas production.

References

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