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Research highlight

Understanding gas transport mechanisms in shale gas reservoir: Pore network modelling approach

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Abstract:
This report summarizes the recent findings on gas transport mechanisms in shale gas reservoir by pore network modelling. Multi-scale pore network model was developed to accurately characterize the shale pore structure. The pore network single component gas transport model was established considering the gas slippage and real gas property. The gas transport mechanisms in shale pore systems were elaborated on this basis. A multicomponent hydrocarbon pore network transport model was further proposed considering the influences of capillary pressure and fluid occurrence on fugacity balance. The hydrocarbon composition and pore structure influences on condensate gas transport were analyzed. These results provide valuable insights on gas transport mechanisms in shale gas reservoir.

1. Main text

The heterogeneities of shale pore system are expressed in terms of complex pore structure and multi-scale pore size (Loucks et al.,2009; Goral et al., 2020). The laboratory core experimental methods can measure the meso-scale transport properties while the detailed pore scale gas transport process is not available (Tian et al., 2022). Therefore, it is essential to study pore scale shale gas transport mechanisms and establish the corresponding flow simulation method (Cai et al., 2022). This work highlights the recent findings on understanding gas transport mechanisms in shale gas reservoir by pore network model (PNM).

The current imaging method is still unfeasible to quantify nano-pores connectivity with micro-pores in a representative elementary volume given the heterogeneities of shale. To deal with this, the shale multi-scale pore network model (MPNM) was proposed with the aim of describing the exact pore throat spatial distribution in a multi-scale pore system (Song et al., 2021). Three-dimensional binary images were constructed by the multiple-point statistics from a section of low-resolution scanning electron microscopy (SEM) image which covers the large-scale pore structure and fine-scale SEM images with the same physical size. The maximal ball fitting method was applied to extract large-scale pore network model (LPNM) and fine-scale pore network models (FPNMs) MPNM was obtained by merging LPNM and FPNMs by preserving the local connectivity between fine-scale pores and large-scale pores in Fig. 1(a).

The pore network single component gas transport model was further established to analyze the gas transport behavior in MPNM. Local-effective-viscosity multi-relaxation-time lattice Boltzmann model was used to study gas transport in irregular nano-pores and a gas flux versus pressure drop solution was derived considering the variation of shape factor, surface roughness, pressure, temperature, and pore size. The gas-bound water distribution at different relative humidity was calculated based on Kelvin's equation considering the van der

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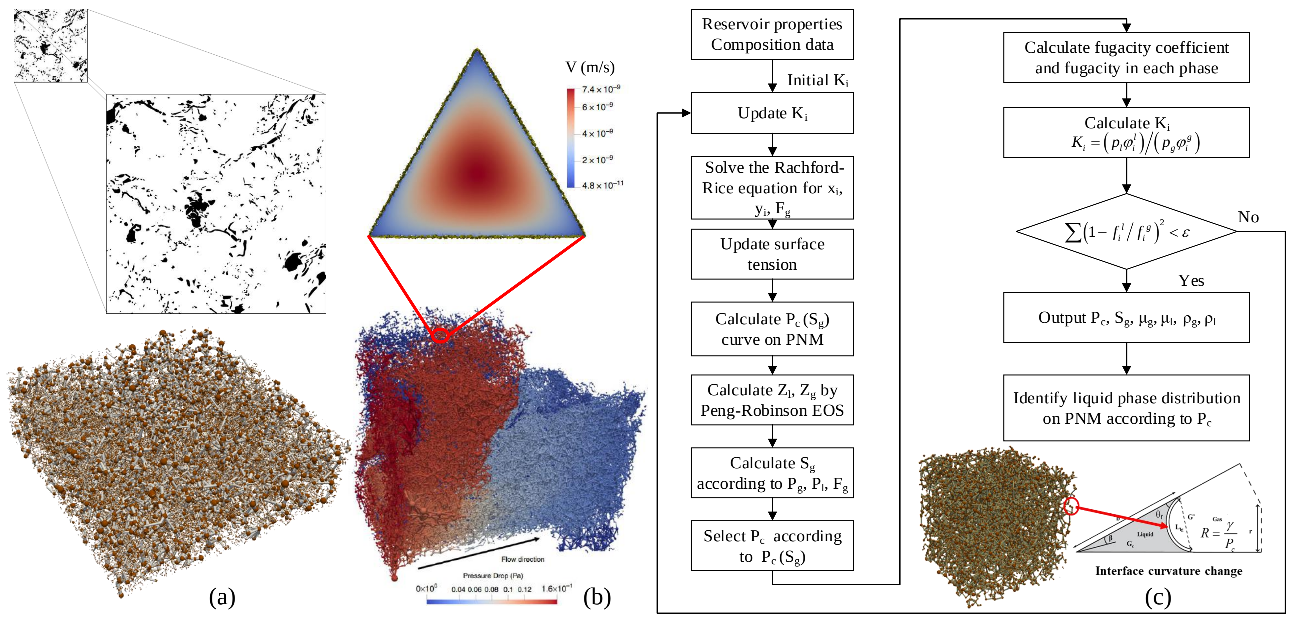

Fig. 1. (a) MPNM, (b) pressure drop distribution on shale PNM, (c) workflow of proposed thermodynamic equilibrium calculation on shale PNM (EOS: equation of state).

Waals force, electric double-layer interactions and structural force. The governing equation on PNM was established based on mass balance principle. It was found that the influence of relative humidity on gas permeability is more pronounced in smaller pores and gas loses its transport ability at average pore radius less than 12 nm and relative humidity larger than 0.7. The gas slip caused by irregular pore shape must be considered especially at low pore pressure and the increase of surface roughness can notably decrease the gas permeability (Song et al., 2021).

Finally, a multicomponent hydrocarbon pore network transport model was proposed to study condensate shale gas transport behavior (Song et al., 2020). A thermodynamic phase equilibrium calculation model was developed considering the influences of capillary pressure and fluid occurrence on fugacity balance (Fig. 1(c)). It was observed that the influence of liquid bridge on gas transport depends on the interplay of hydrocarbon composition, pressure, temperature, pore shape, pore size as well as contact angle. In summary, the systematic single component and multicomponent pore network transport models were proposed to understand gas transport mechanisms in shale and the detailed pore scale gas transport process during field production was elucidated.

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Conflict of interest

The authors declare no competing interest.

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