Modeling Immiscible Fluid Displacement in a Porous Medium Using Lattice Boltzmann Method

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INTRODUCTION

The increase in greenhouse gas (GHG) concentration in the atmosphere over the past decades has generated strong interest in developing technologies that help in reducing CO_2 emissions. Carbon Capture and Storage (CCS) is an emerging field of research that is viewed as one of the potential solutions to decrease CO_2 concentration in the atmosphere.

AIM

The study aims to improve understanding of the interaction between the physical parameters involved in complex multiphase flow in porous media (e.g., CO2 sequestration in aquifers).

OBJECTIVES

Study the displacement of the non-wetting phase by wetting phase in porous media under different flow conditions and pore geometries using Lattice Boltzmann Method (LBM)

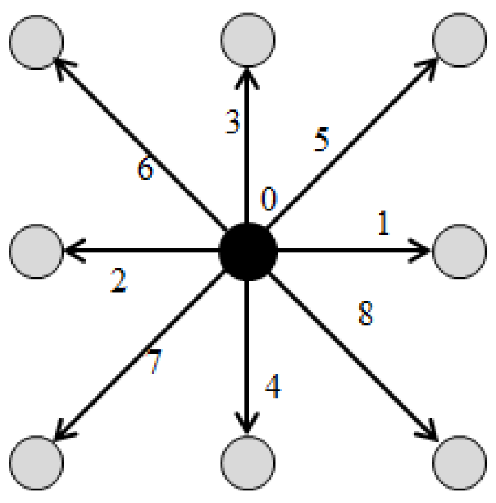
METHODOLOGY

- Lattice Boltzmann Method

Single distribution function:

$$f_i(x + e_i\Delta t, t + \Delta t) = f_i(x,t) + \Omega_i(f(x,t), (i = 0, 1 \dots, M)$$

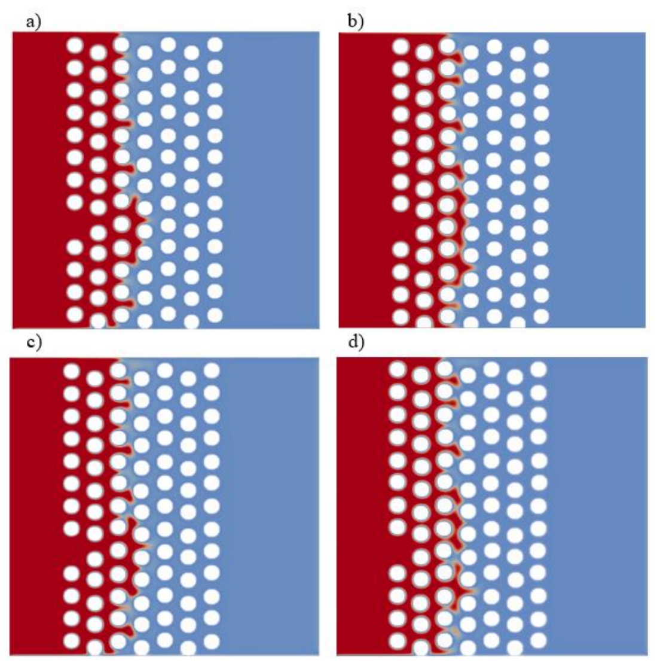
The left side of equation is the streaming step and the right side is collision operator.



	Weighting factors for D2Q9
i	w_i
0	4/9
2,4,6,8	1 /9
1,3,5,7	1/36

Modelling the porous media with conventional Computational Fluid Dynamics (CFD) tools due to the complex geometries involved, including small length-scale pores, and, hence, the required use of a computationally prohibitive adapted mesh. The LBM models macroscopic fluid parameters based on its microscopic characteristics but avoids tracking every single molecule. Additionally, LBM is not limited to the time and length-scale.

RESULTS

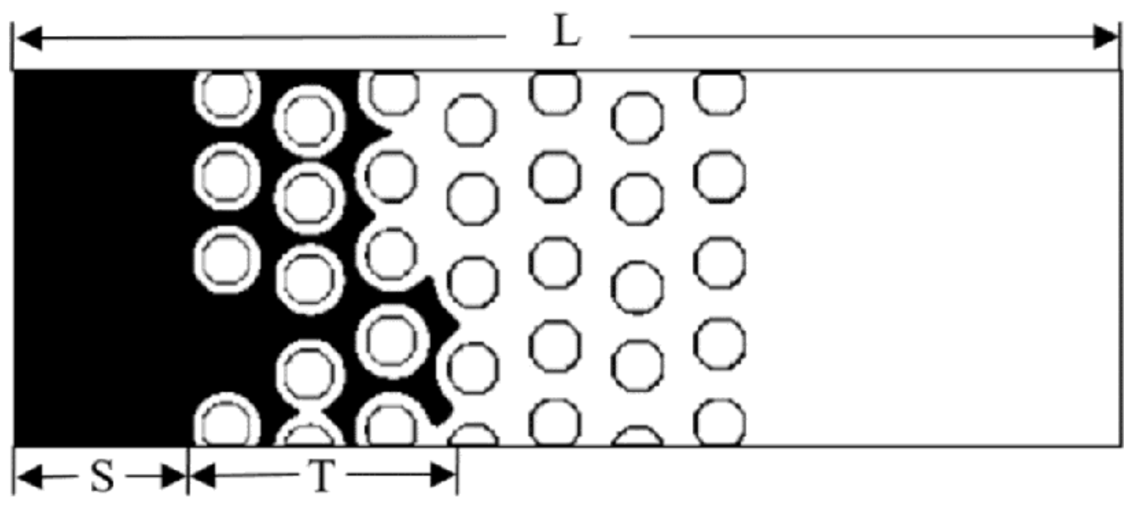


Numerous simulations were conducted to analyze the influence of Capillary number, viscosity ratio and surface wettability on the gaseous phase penetration effectiveness.

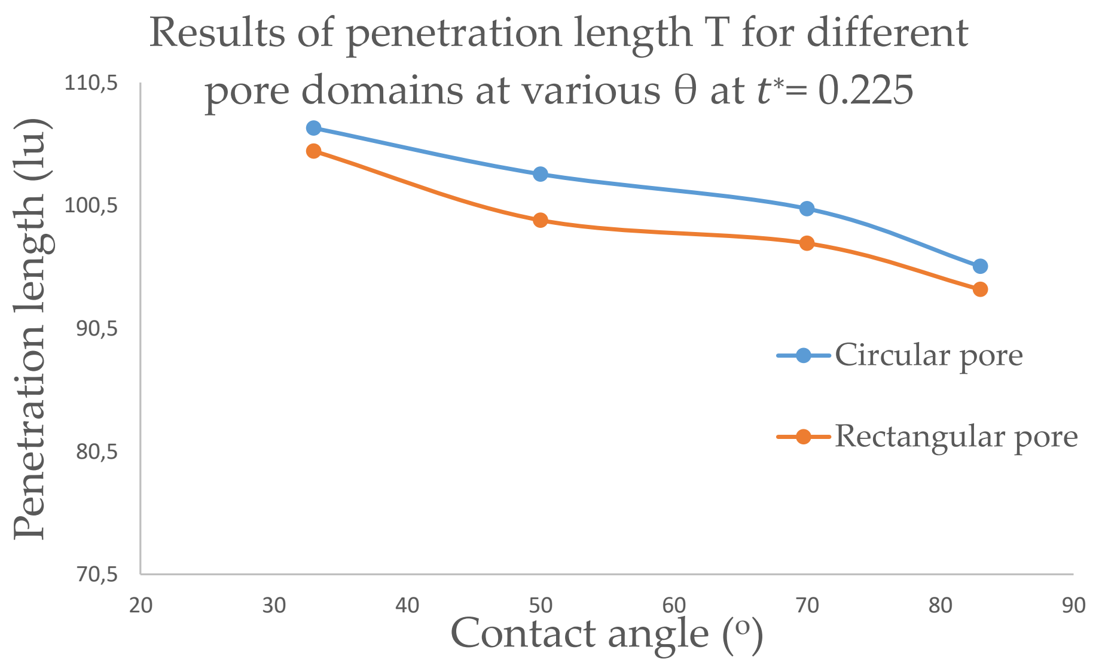
Higher Ca favors faster penetration of the gaseous phase into the porous media. At low D, the fingering narrows and spreads sideways faster, while it locally thickens when D increases

Pore Geometry	Capillary number	Penetration length (lu)
Circular	0.038	84.322
Square	0.038	93.691
Circular	0.076	89.931
Square	0.076	97.447
Circular	0.115	92.812
Square	0.115	103.107

Comparison of effective penetration length T for different pore geometries at different Ca and f* = 0.175.



The effective gas penetration, measured by length T. The domain length (L), the slip distance (S) In all cases the slip distance is the same.



The effective gas penetration in the circular-pore domain is higher than that in the square-pore domain due to the narrower inter-pore pas-sages

CONSLUSIONS & RECOMMENDATRIONS

The Peng–Robinson EOS integrated into LBM enables the modeling of the gas penetration phenomenon with a liquid–gas. density ratio of 5, resulting in negligible instabilities (i.e., spurious currents) at the interface. The velocity-shift and EDM forcing schemes have the same stability conditions at τ = 1. Increasing the capillary number (Ca) and surface wettability enhanced the effective gas penetration at constant viscosity ratio D, while an opposite effect is noticed when increasing D whilst maintaining constant Ca and wettability. The effective gas penetration was higher in the square pore domain than that in the circle-pore domain by approximately 10% and 4% with respect to Ca and D accordingly.

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