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Multiphase thermal-fluid flow through geothermal reservoirs

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Abstract

Recently, Lattice Boltzmann Modelling (LBM) techniques attract many scientists in various fields of research. This study shows the capability for LBM to simulate the fluid flow and heat transport in porous and fractured media, which is an important process in natural aquatic environments, water treatment, and other water-related technologies. LBSim was used in this work as Lattice Boltzmann Model simulator software. In this study, a series of synthetic cases were presented to show the capability of the method in simulating the fluid flow and heat transfer in porous/fractured media. Results show that LBSim delivers reliable and helpful simulation. Thus, LBSim is a recommended tool for simulating fluid flow whether it is laminar or turbulent, and for heat and mass transport under complex geometry and boundary conditions and parameter values.

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1. Introduction

In 1988, McNamara and Zanetti introduced LBM. LBM is originally from Lattice Gas Automata (LGA) method [1]. The main reason for the switch from LGA to LBM was the need to eliminate the statistical noise by a density distribution function [2] and collision operator replaced a discrete collision rule. The most important simplification is using Bhatnagar-Gross-Krook (BGK) to approximate the collision operator [3].

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LBM is a special class of CFD. In contrast to traditional CFD techniques that solve the conservation equations for macroscopic properties, LBM is a rooted macroscopic model that contains particles, which can only move along a finite number of directions [4, 5]. It is an alternative method for solving the Navier-Stokes equations. LBM is considered as an explicit method [5]. However, it is the newest simulation technique for complex flow and transport problems.

The main principle of LBM is that the fluid is substituted by fictive particles [5]. Every particle flows in a certain direction and collides at the lattice location (Fig. 1) [5]. Many different Lattice Boltzmann models already exist. The most popular method for 2D simulation is D2Q9, while for 3D simulation D3Q15, D3Q19, and D3Q27 are commonly used. Dn indicates the number of dimensions and Qn means a number of velocities per a lattice site (e.g. D2Q9 is a two dimensional LBM with nine velocities). Figure 1 shows D2Q9 and D3Q19 model.

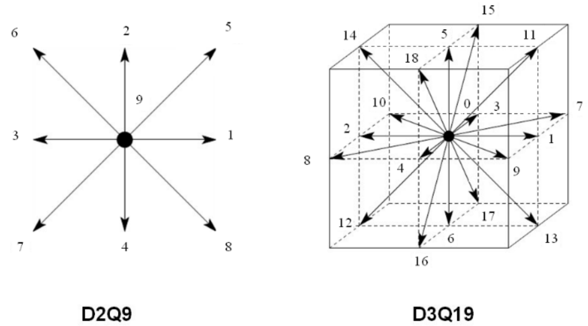

Fig. 1. Difference between D2Q9 and D3Q19 [6].

LBM has several advantages in comparison to normal CFD approaches, particularly, in dealing with complex geometry and physics, integrating microscopic interactions and, parallelization of the algorithm [5, 7]. It is also relatively easy to implement in complex hardware architecture. In fact, the main advantage is that the pressure field is directly calculated from density distribution and therefore there is no need for Poisson's equation as is the case with CFD methods [5, 7]. Furthermore, it is not difficult to handle multi-component and multi-phase flow with LBM [5]. The main drawback of LBM is high-Mach number flows in aerodynamics [8] and it requires more memory compared to solving Navier-Stokes equations with classical methods [5].

LBM has attracted the attention of researchers and scientists around the world and it has been used in a large number of researches (e.g. Kang et al. [9], Kang et al. [10], Kang et al. [11], Sukop and Thorne [12], Yoshida, Nagaoka [13], Zhang et al. [14], Zhang et al. [15], Zhang et al. [16], Hidajat et al. [17], Zhang and Ren [18], Abdelaziz et al. [19], Abdelaziz [20], Abdelaziz and Komori [21], Chapman et al. [22], Yamabe et al. [23], and Zi-Xiang [24]). LBM was used in several applications e.g., Anwar and Sukop [25] used Lattice Boltzmann algorithm to simulate solute transport in karstified rocks. Madadi and Sahimi [26] employed LBM to model fluid flow through a fracture network, while Kang et al. [9] used it to emulate fluid flow and solute transport and Abdelaziz et al.[19] used LBM to simulate solute transport in fractured aquifer. Recently, Gao et al. [27] used it to improve emulation and evaluation of fluid flow in heterogeneous porous media by multiple matrix constituents. They investigated the impact of geometric topology and matrix property on the velocity. Currently, a variety of LBM software systems are available as open source software like J-Lattice-Boltzmann, LB2D, LB3D, EL'Beem, SunlighLB, OpenLB, LIMBES, LBSim, Palabos, LBM-C, Taxila LBM and , Sailfish. There are also several commercial software systems available like PowerFLow, XFlow, FlowKit, LBHydra and, utraFluid. More information about LBM principles and applications can be found in [5, 12, 20].

In this work, a series of cases using the Lattice Boltzmann method are presented, showing the capability of the method in simulating phenomena with fluid flow and heat transfer in porous and fractured media.