ISSN: 2687-8097

Scientific Journal of Research and Reviews

DOI: 10.33552/SJRR.2025.04.000596

Iris Publishers

Opinion

The Qadyan Method, A Powerful Tool for Simulating Fluid Flows

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Received Date: October 27, 2025

Published Date: November 13, 2025

Abstract

Most researchers in computational fluid dynamics (CFD) realize by now that both accuracy and numerical stability are needed to successfully simulate the remaining problems. This 2-page Opinion proposed a new approach to the lattice Boltzmann model (LBM) for simulating fluid dynamics problems. New methods are needed for sustainable success in a world of constant technical change.

Keywords: LBM; DQM; Qadyan method; Discrete velocity models; CFD

Finding a Sustainable, High-accuracy, and High-performance Method: It's not easy

Lattice Boltzmann method (LBM), unlike the traditional methods, which solve directly the Navier-Stokes Equations (NSE), this method is based upon solving mesoscopic kinetic variables (Boltzmann Equation) for the particle distribution functions. The widely used Bhatnagar-Gross-Krook (BGK) of LBM with collision-streaming processes, which utilizes single-relaxation-time (SRT), has its limitations in solving engineering problems despite its advantages over NSE solvers. One of the limitations of the BGK-LBM is its confinement to uniform grids with equal spatial steps in solving engineering problems. Unlike traditional NSE solvers, the LBM describes physical phenomena using a phase-space discretized version of the Boltzmann equation. The velocity discretization of particle distribution functions in the standard lattice Boltzmann method (SLBM) is strongly influenced by the lattice structure. To obtain higher-order accuracy in the LBM, some researchers employed the finite difference lattice Boltzmann method (FDLBM) to remove the influence of the lattice structure. Some researchers used two distribution functions consisting of the density distribution function and the energy distribution function in their work. These distribution functions were used for solving the continuity-momentum and energy equations. They also used the conditions of a higher number of relaxation times to obtain the new equilibrium conditions [1]. The more common methods employed for enhancing stability include the Entropic Lattice Boltzmann (ELB), Two-Relaxation-Time (TRT), and the Multi-Relaxation-Time (MRT) model. Generally, there are two approaches to obtain higher-order accuracy in the LBM. The first approach is to modify the discrete velocity models of the LBM, and the second approach is to find practical methods for the numerical solution of the Boltzmann equation. Considering the first approach, the significant errors in the

LBM can be reduced in modified discrete velocity models, and the elimination of numerical oscillations in the numerical method. The second approach solves the discrete velocity Boltzmann equation in its original differential form via a variety of numerical methods, including finite-difference, finite-volume, and finite-element methods. This allows for separate discretization of the phase space and the velocity space and enables LBM to handle computational performance more easily. Some numerical experiences show that the second-order finite difference scheme for the calculation of the space derivative causes oscillations in the numerical solution. The differential quadrature method (DQM) has been projected as a potential alternative to conventional numerical solution techniques such as the finite difference and finite element methods. Since the Qadyan method, due to the nature of the differential quadrature method, utilizes more combinations of candidate stencils, the second approach will be assessed here.

Differential Quadrature Lattice Boltzmann Method

The Qadyan method, also known as the Differential Quadrature Lattice Boltzmann Method (DQLBM), offers opportunities in simulating fluid flows by enhancing the robustness and accuracy of the Lattice Boltzmann Method (LBM). It combines semi-discrete schemes with the differential quadrature method to solve partial differential equations. This approach allows for more accurate results compared to traditional methods like the finite-difference lattice Boltzmann method, especially in scenarios involving complex geometries and boundary conditions. The efficiency of the Qadyan method has been investigated and verified in comparison with other numerical methods and analytical solutions, showing acceptable agreement. The Qadyan method is based on the D2Q9 arrangement, is better to implement, and has stronger accuracy and stability features. From the accuracy point of view of the usual discrete velocity models in simulating problems to larger stencil grids required by the Qadyan method are more efficient than FDLBM and SRT-LBM [2].

Here's a more detailed breakdown of the opportunities:

Enhanced Accuracy and Robustness

The Qadyan method provides more accurate results compared to traditional LBM methods, particularly when dealing with complex flow phenomena like those in heat transfer and fluid dynamics. It achieves this enhanced accuracy without requiring a significant increase in computational resources, making it a valuable tool for simulations where precision is critical [3].

Improved Simulation of Complex Flows

The method is particularly well-suited for simulating flows in complex geometries, such as those found in microfluidics, porous media, and other challenging environments. It can handle a wider range of flow conditions and boundary conditions, making it suitable for a broader spectrum of applications [4].

Potential for Higher-Order Accuracy

The Qadyan method's foundation in the differential quadrature method allows for the potential to achieve higher-order accuracy in simulations, leading to more precise predictions of flow behavior.

Reduced Computational Cost

While the Qadyan method can have a higher computational cost than some simpler LBM approaches, it offers a better balance between accuracy and computational efficiency, especially when compared to methods that require extensive grid refinement [5]. In essence, the Qadyan method provides a powerful tool for simulating fluid flows with improved accuracy and robustness, making it a valuable technique for researchers and engineers working in various fields of fluid dynamics [6, 7].

Conclusion

From the theoretical point of view, significant errors in D2Q9 FDLBM may arise from the non-zero weighing coefficient of a particle residing at the center of the lattice. A rest particle at the center of the lattice, owing to its fixed nature, doesn't reveal compatibility with the upwind discretization in the finite difference method. According to our numerical experiences, D2Q9 FDLBM for unsteady problems did not improve numerical accuracy, especially without using clustered meshes. To seek a solution using the D2Q9 arrangement, the simulations underscored the efficacy of the Qadyan method, showcasing commendable harmony with analytical solutions.

Acknowledgments

This work was supported, in part, by the Islamic Azad University of Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, and by the Karaj Branch of the Islamic Azad University. The authors appreciate all the supporters of this work.

Conflict of Interest

None.

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