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Modelling Fluid Flow over a Physical Barrier using Lattice Boltzmann Method

Isabel E G Connor
Department of Natural Sciences, University of Exeter, UK

Abstract: Heat transfer from solids into a fluid flow is an important due to its applications within heat exchangers, such as thermal energy storage from solar energy. As energy consumption continues to increase, minimising energy loss during heat transfers is of utmost importance to decrease the contribution to the climate crisis. The Lattice Boltzmann method (LBM) has proven successful for modelling 2D non-isothermal flows and 3d isothermal flows. Using LBM to model the impact of complex geometries that force vortices around a heating component will help develop technologies that minimise energy loss.

1 - Introduction

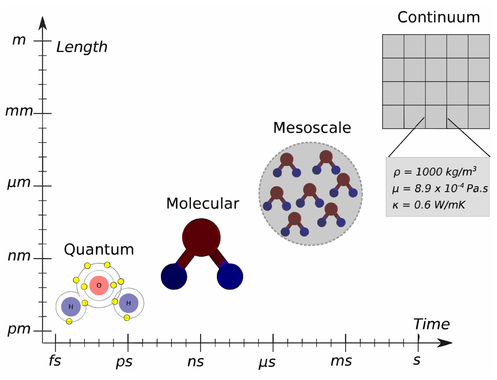


Fig 1: Scale comparison of computational fluid dynamic models from D.Drikakis[1].

- Classic computational fluid dynamics models operate on the continuum level (Fig 1). Physical phenomena, such as no-slip conditions, are difficult to model.
- Lattice Boltzmann works on the mesoscopic scale but can still retrieve macroscopic hydrodynamic properties.
- Understanding heat transfer across the solid-fluid interface is vital as energy consumption continues to increase.

2- Lattice Boltzmann Method

- Lattice Boltzmann Method (LBM) is a numerical modelling technique based on kinetic equations[2].
- Particle density is determined by distribution functions rather than tracking individual particles like in molecular dynamics.
- Particle movement is limited to lattice nodes.
- Lattice described by DdQq (d-dimensions, q- velocities), such as D2Q9 (Fig 2).
- Able to execute large-scale computational parallelisation.

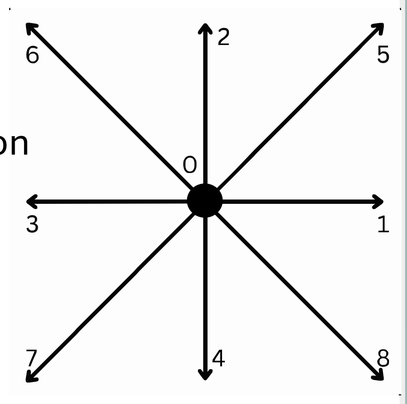


Fig 2: Image of D2Q9 LBM lattice scheme

3 – Heat Transfer within LBM

- Double distribution functions, one tracking density distribution and another tracking internal energy allows non-isothermal flows to be modelled[2].
- Conventional Navier-Stokes-based methods require separate schemes for solid and fluid.
- LBM's use of kinetic equations eliminates the need for separate schemes for different phases.
- Fig 3 demonstrates an implementation of natural convection in between a hot (left) wall and cold (right) wall[4].

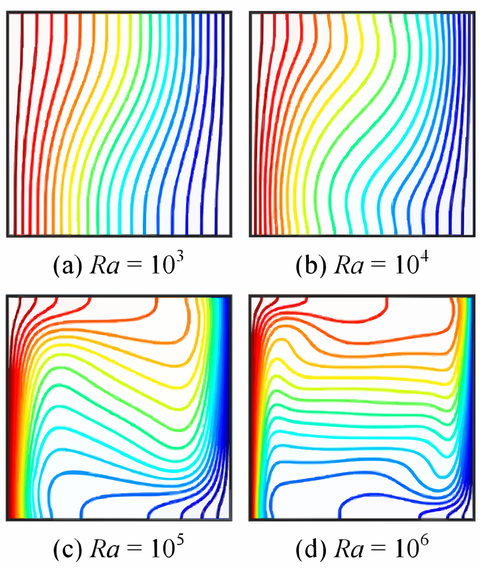


Fig 3: Isotherms for Natural Convections for $Ra = 10^3, 10^4, 10^5, 10^6$ taken from X.Ren[4].

4 – Lid Driven Cavity Flow

- Lid-driven cavity flow is commonly used as a benchmark for incompressible fluid flow[5].
- Fig 5 demonstrates the schematic for lid driven cavity flow.
- Fig 6 shows the velocity profile of lid driven cavity produced from LBM for an isothermal fluid.
- Bounce back boundary conditions are used and produce a consistent benchmark compared to the current literature[5].

Fig 5 (right): Schematic of lid-driven cavity flow taken from T.Huang[5].

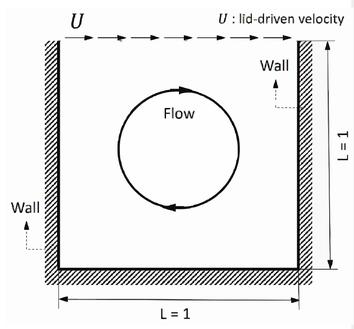
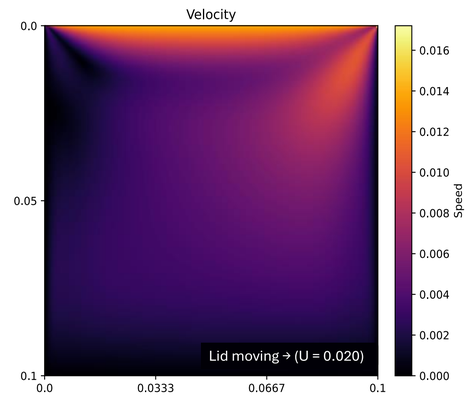


Fig 6 (below): Lid-driven cavity flow at U = 0.020 m/s, time = 24.0 s.



5 - Fluid flow over a physical barrier

- Physical barriers are a common way of forcing heat transfer.
- Fig 7 shows the fluid flow interacting with a circular solid barrier.
- Bounce back boundary conditions are imposed upon the circle.
- No heat transfer occurs in Fig 7, but the barrier interaction intuitively makes sense.
- Looking at the schematic in Fig 8, recirculation zones occur when the flow interacts with a step.
- Recirculation zones can be assumed to act as heat sinks and impact the overall heat transfer.
- In 3D, recirculation zones can be assumed to occur perpendicular to the 2D simulation plane.
- Understanding this phenomenon will allow more efficient heat transfer technologies to be developed.

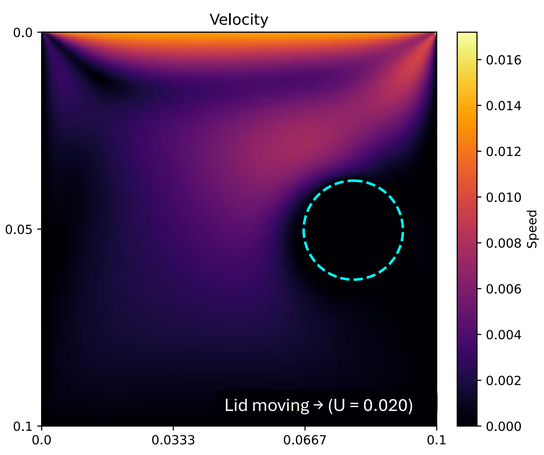


Fig 7: Map of lid driven cavity flow with a solid circular barrier.

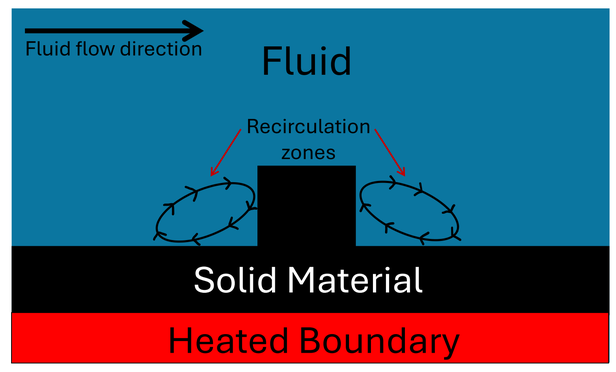


Fig 8: 2D schematic of the 3D problem that will be investigated.

4 - 3-Dimensional LBM

- D3Q19 (Fig 4) lattices can be implemented for 3D LBM which allows more applicable geometries to be investigated.
- LBM's flexible handling of complex geometries due to its natural accommodation of momentum and thermal transport due to its distribution functions makes it desirable over other methods.

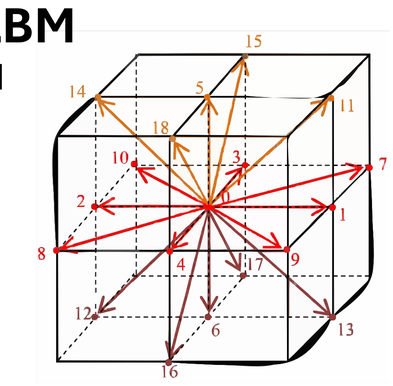


Fig 4: D3Q19 lattice scheme for 3D LBM.

6 – Final remarks and future work

- LBM is effective at modelling heat transfer over a solid-fluid interface due to its use of kinetic equations.
- Future work will focus on extending a thermal scheme into 3D to investigate the impact vortices and eddies have upon heat transfer when fluid flows over a heated step.
- In order to verify the reliability of the model, other computational fluid dynamics methods, such as OpenFOAM, will be used to simulate the same scheme. Allowing a comparison of computational efficiency as well.
- A clearer understanding of heat transfer over the fluid-solid interface will benefit the development of efficient heat transfer technologies.

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