Thermal lattice Boltzmann method for multiphase flows

Dmitry Medvedev, Lavrentyev Institute of Hydrodynamics, Novosibirsk, Russia
Alexander Kupershtokh, Lavrentyev Institute of Hydrodynamics, Novosibirsk, Russia
Igor Gribanov, Novosibirsk State University, Russia

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The Lattice Boltzmann method (LBM) is widely used to simulate fluid flows. The evolution equation for the discrete velocity distribution functions is

$$f_k(\mathbf{x},t) = f_k(\mathbf{x} - \mathbf{c}_k\Delta t, t - \Delta t) + \Omega_k(\{f\}) + \Delta f_k.$$

Here, Δf_k is the change of distribution functions due to action of volume forces. It is calculated using the exact difference method (EDM) [1] as $\Delta f_k = f_k^{eq}(\rho, \mathbf{u} + \Delta\mathbf{u}) - f_k^{eq}(\rho, \mathbf{u})$, where $\rho\Delta\mathbf{u} = \mathbf{F}\Delta t$.
A heat transfer is usually simulated in LBM as an advection of a passive scalar by the use of additional set of distribution functions which has smaller numerical diffusion than finite-difference methods. For the flows with nearly constant density, the temperature was used as a passive scalar. For the flows with phase transion liquid–vapor, the change of density is large, and the transport of internal energy density $E = \rho c_V T$ should be considered instead of temperature

$$\frac{\partial E}{\partial t} + \nabla\cdot(E\mathbf{u}) = \frac{P}{\rho}\frac{d\rho}{dt} + \nabla\cdot(\kappa\nabla T). \qquad (1)$$

In this case, the traditional method produces significant diffusion over phase boundaries (since gradients of energy density are large there) leading to unphysical temperature increase in the gas phase.
In present work, we introduce the modified method of additional distribution functions which is free of this drawback. The idea is to add special "pseudoforces" which counteract the spread of energy near phase boundaries. The action of "pseudoforces" in evolution equation for the additional distribution functions is taken into account using the EDM. The pressure work and the heat conduction are calculated by finite differences. Figure 1 shows the simulation results for a stationary droplet with the constant temperature T. The new method maintains the energy distribution and preserves the uniform density, whereas without "pseudoforces", the parasitic diffusion and unphysical temperature peaks are clearly visible.

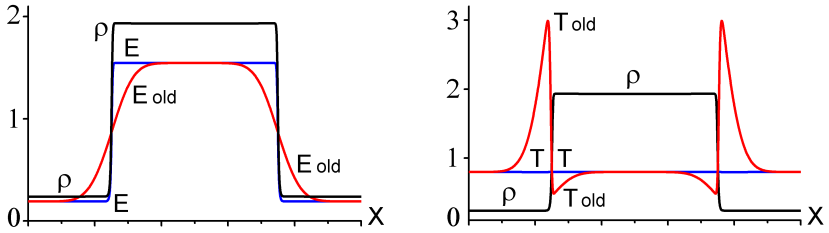

Fig. 1: *One-dimensional droplet in a saturated vapor. Parasitic diffusion of the internal energy (E_{old}) without "pseudoforces" for barotropic equation of state $P = P(\rho)$*

References

[1] Kupershtokh A.L. – *Criterion of numerical instability of liquid state in LBE simulations.* – Computers & Mathematics with Applications, **59**, pp. 2236–2245, 2010.

Dmitry Medvedev, Lavrentyev Institute of Hydrodynamics, Lavrentyev prosp. 15, 630090 Novosibirsk, Russia
dmedv@hydro.nsc.ru
Alexander Kupershtokh, Lavrentyev Institute of Hydrodynamics, Lavrentyev prosp. 15, 630090 Novosibirsk, Russia
skn@hydro.nsc.ru
Igor Gribanov, Novosibirsk State University, Pirogova str. 2, 630090 Novosibirsk, Russia