Commun. Comput. Phys.
doi: 10.4208/cicp.291011.270112s

Vol. **13**, No. 3, pp. 685-695
March 2013

Lattice Boltzmann Simulation of Cavitating Flows

Giacomo Falcucci[1,*], Stefano Ubertini[2], Gino Bella[3] and
Sauro Succi[4]

[1] *Department of Technologies, University of Naples "Parthenope", Centro Direzionale - Isola C4, 80143 Naples, Italy.*
[2] *DEIM - Industrial Engineering School, University of Tuscia, Largo dell'Università s.n.c., 01100, Viterbo, Italy.*
[3] *Department of Mechanical Engineering, University of "Tor Vergata", Viale Politecnico, Rome, Italy.*
[4] *Istituto per le Applicazioni del Calcolo - CNR, Via dei Taurini, 00100 Roma, Italy.*

Received 29 October 2011; Accepted (in revised version) 27 January 2012

Abstract. The onset of cavitating conditions inside the nozzle of liquid injectors is known to play a major role on spray characteristics, especially on jet penetration and break-up. In this work, we present a Direct Numerical Simulation (DNS) based on the Lattice Boltzmann Method (LBM) to study the fluid dynamic field inside the nozzle of a cavitating injector. The formation of the cavitating region is determined via a multi-phase approach based on the Shan-Chen equation of state. The results obtained by the LBM simulation show satisfactory agreement with both numerical and experimental data. In addition, numerical evidence of bubble break-up, following upon flow-induced cavitation, is also reported.

PACS: 47.11.-j, 47.65.Cb

Key words: Lattice Boltzmann, multiphase flows, cavitation, liquid spray, nozzle.

1 Introduction

The use of some form of liquid sprays is very common in industrial processes. Therefore, there is a constant demand and a very high scientific interest in liquid atomization, as the spray characteristics are crucial to the success of the particular industrial application. A remarkable example is represented by direct injection internal combustion engines, whose efficiency and pollutant emissions are significantly affected by the fuel spray characteristics [1, 2]). However, the understanding and the numerical simulation of liquid

---

[*] Corresponding author. *Email addresses:* `giacomo.falcucci@uniparthenope.it` (G. Falcucci), `stefano.ubertini@uniparthenope.it` (S. Ubertini), `bella@uniroma2.it` (G. Bella), `succi@iac.cnr.it` (S. Succi)

spray formation is a very challenging task as it involves several complex phenomena. A liquid spray is a collection of fine liquid dispersed droplets generated by injecting a liquid fuel in a gaseous environment (i.e. fuel spray in an engine cylinder) through a nozzle. The flow conditions inside the nozzle are deeply influenced by both injection pressure and nozzle dimensions. Under particular conditions, as for example in diesel injection systems, liquid velocity inside the nozzle may be very high and the static pressure may locally drop below vapor pressure, leading to *cavitation*, which is to say the formation of cavities or gas bubbles in the liquid. The simulation of this phenomenon is a very challenging task, but is crucial for a proper modeling of the subsequent spray. Experimental works in literature, in fact, have demonstrated that the rising of cavitation significantly influences the atomization process of a liquid spray [3–6]. On the other hand, due to the complexity of the involved phenomena, only few theoretical and numerical studies of nozzle flow cavitation are available in literature [7].

The aim of this work is to test the Lattice Botlzmann Method (LBM) as a possible candidate to study the onset of cavitation inside a nozzle. LBM is a numerical method to investigate fluid dynamic fields; it is not based on the continuum assumption as the Navier-Stokes (NS) approach, but rather on the notion of particle distribution functions, as developed Boltzmann's kinetic theory. In recent years, LBM has been successfully employed to study both single-phase fluid dynamics and complex phenomena, like multiphase/reacting flows [8–11], fluid-structure interaction [12], and also bubble cavitation [13, 14].

In a recent work, the authors successfully employed the LBM to model the break-up of a liquid spray [15], for different values of Reynolds and Weber numbers. The multiphase nature of the flow has been modeled through the approach proposed by Shan and Chen [16, 17]. In this work, LBM coupled to Shan-Chen model is employed to simulate the flow and the onset of cavitation inside a nozzle with simplified geometry under realistic conditions, including the dynamics of the injector pintle. To the best of our knowledge, this is the first Direct Numerical Simulation (DNS) of a flow-induced cavitation using the LB method.

Different cavitation phenomena are reproduced, depending on the dynamic schedule of the injector; in particular for the case where such dynamics takes into account the fluid and pintle inertia, cavitation is found to be followed by break-up phenomena in the nozzle.

2 Numerical method

The Lattice Boltzmann Method (LBM) is a numerical approach to investigate fluid dynamic phenomena based on a minimal discrete form of Boltzmann's kinetic equation [18]. The basic equation of this method reads as follows,

$$f_i(\vec{r}+\vec{c}_i\delta t;t+\delta t)-f_i(\vec{r},t)=-\omega\delta t\,(f_i-f_i^{eq})+F_i\delta t \tag{2.1}$$