Analysis of pressure drop in blood vessels with a barrier of moving blood clots using the Lattice-Boltzmann Method.

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Desarrollo de la ingeniería y arquitectura para el diseño y construcción de un futuro sostenible

ABSTRACT

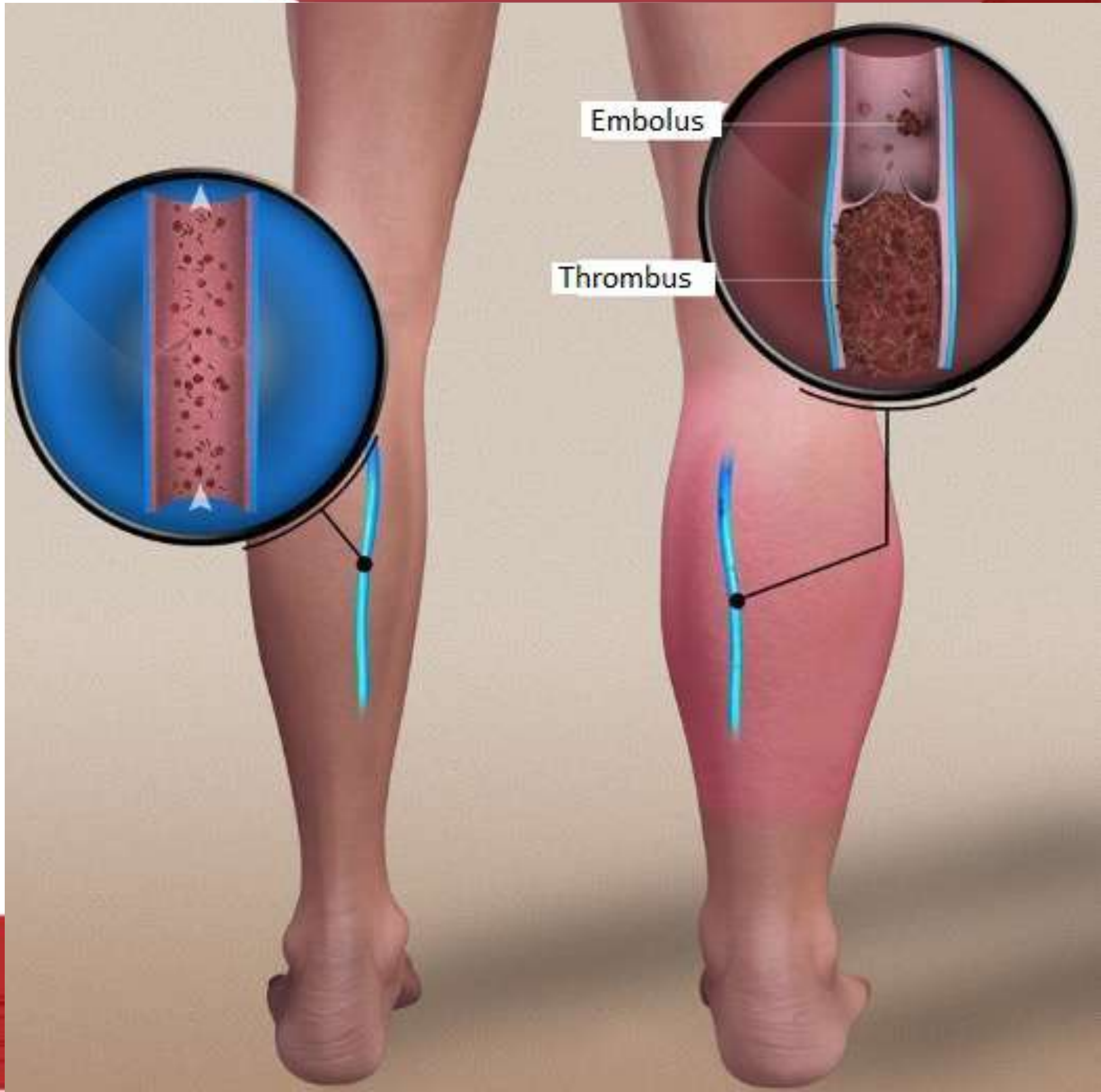
- It is analyzed a small thrombus just after the moment it breaks up
- Numerical calculations are performed with a computer model of a flow through a pipe with an obstacle therein.
- Temporal behavior of pressure drop and velocity of blood through moving clots is studied.

ABSTRACT (Cont.)

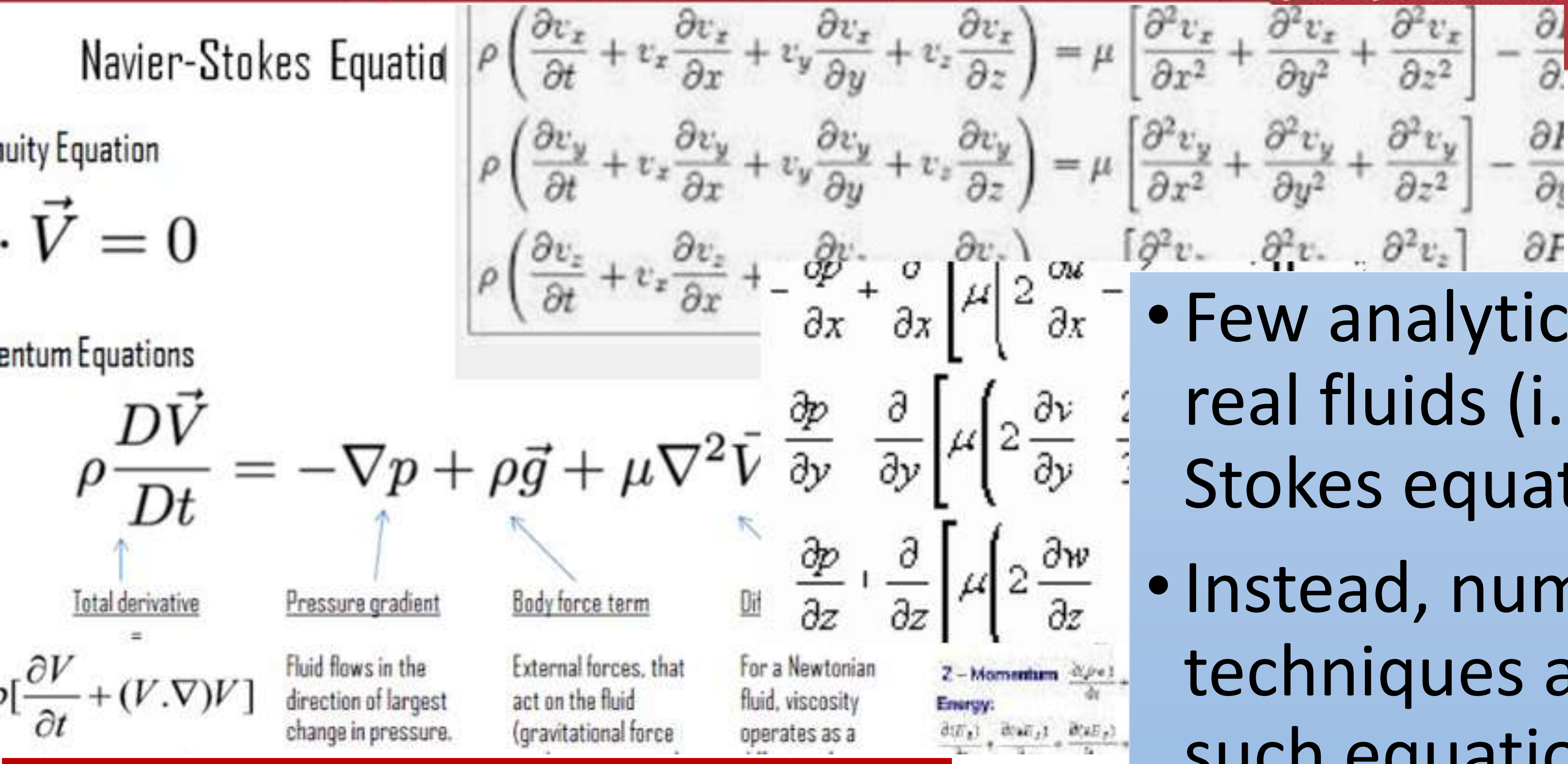
- Relationships between the variation of the obstacle effective area and the pressure drop is found.
- The pressure variation measured before and after the moving obstacles region only depends on the temporal change of the effective dry area of obstacle.

Thrombosis Condition

- Thrombosis is the formation of a blood clot in a blood vessel.
- Figure shows a vein in its normal state as well as one having a thrombus.
- The clot can break loose and travel to another place in veins.



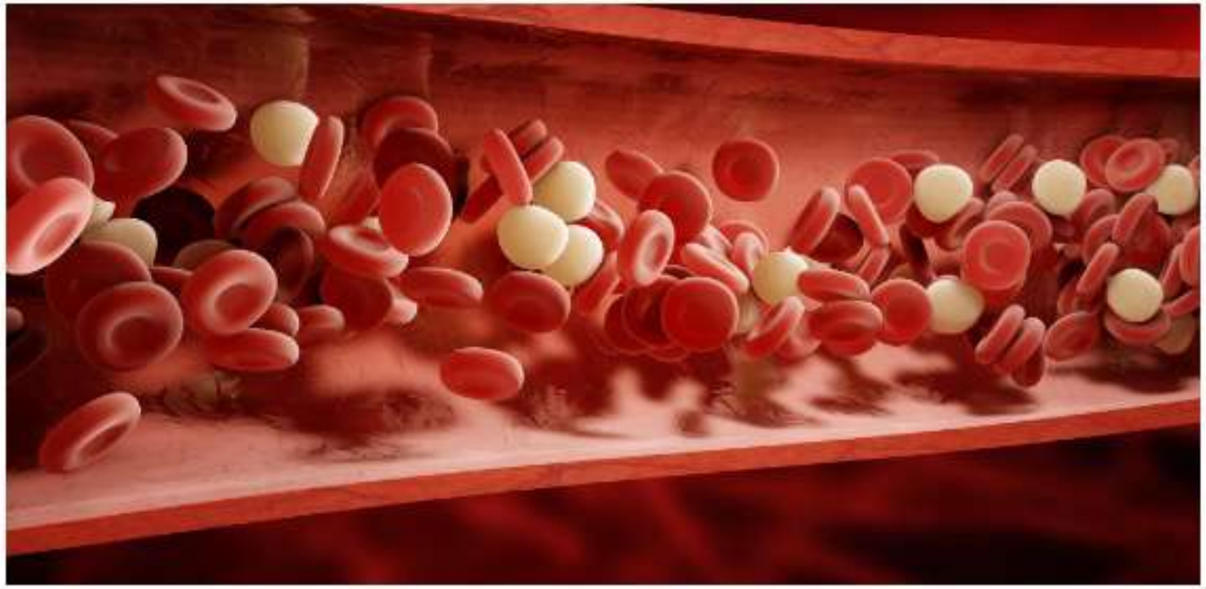
FLUIDS

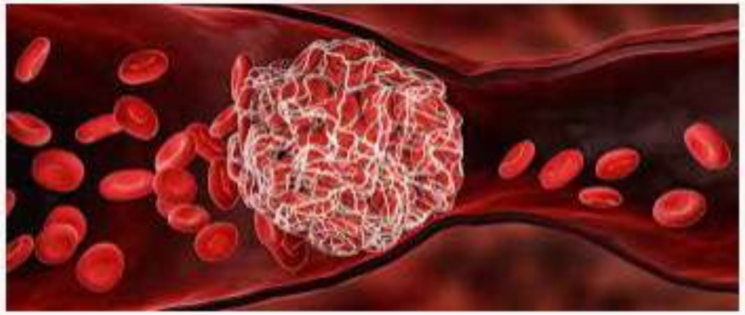


- Few analytical solutions for real fluids (i.e. Navier-Stokes equations).
- Instead, numerical solution techniques are used: solve such equations using **the Lattice-Boltzmann Method** (**LBM**).

The Model

- The temporal evolution is studied using the Lattice-Boltzmann method.
- The moving particles have autonomous random motion, producing time-varying intermittent thin streams through which the blood travels.





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The Model (Cont.)

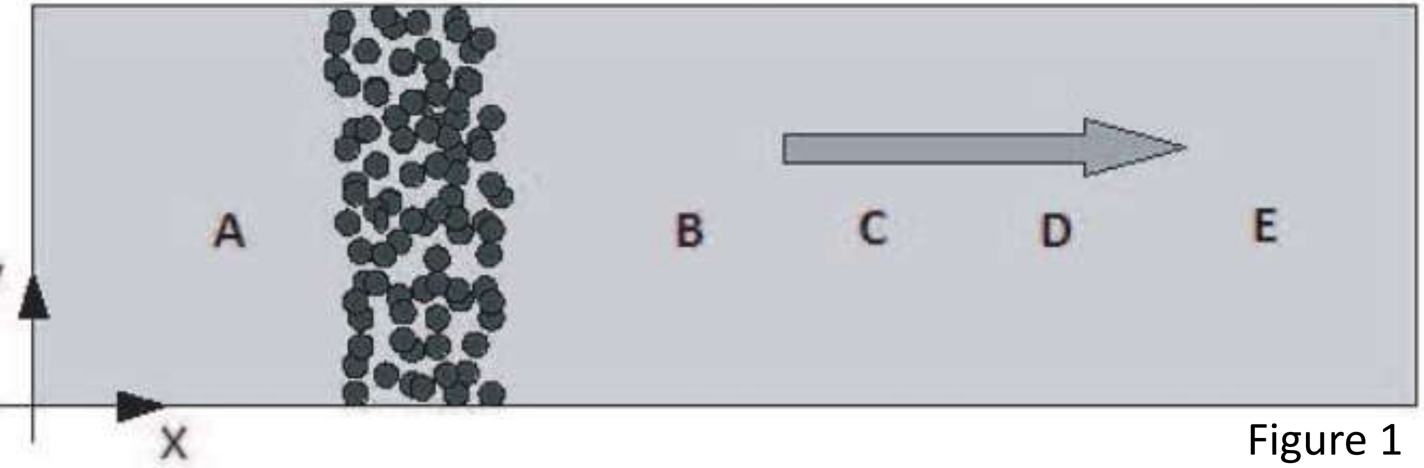


Figure 1

- Two-dimensional model. The strip obstacle is made up of small grains, so the effective area varies in time. Points with labels A, B, C, D and E are locations to get samples of variables.

- The LBM is especially useful for modeling **complicated** interfaces and **boundary conditions**, as well as **moving frontiers**.

The Model (Cont.)

- The scale of analysis is the size of clots, about 5% of a typical vein diameter.
- Clots displacements are assumed to obey a Uniform Probability Distribution Function (2D).
- System is modeled with a two-dimensional long tube with rectangular geometry of size $L_y = 400$ nodes high, and $L_x = 3000$ nodes wide; both dimensions in lattice units [a.u.].

Lattice Boltzmann Algorithm

- The Boltzmann equation is described in terms of the probability distribution function *f* of the particles at the time *t* located at position *x* with velocity **ξ** defined by

$$\frac{\partial f}{\partial t} + \boldsymbol{\xi} \cdot \frac{\partial f}{\partial \mathbf{x}} + \boldsymbol{F} \cdot \frac{\partial f}{\partial \boldsymbol{\xi}} = \Omega(f) \tag{1}$$

where Ω(*f*) is the collision operator which models the interaction between particles.

Lattice Boltzmann Algorithm (Cont.)

- For an average time τ between a pair of particle-collisions, the collision term $\Omega(f)$ is defined by $\Omega(f) = -(f - feq)/\tau$, and the function f^{eq} is

$$f^{eq} = \frac{\rho}{(2\pi c_s^2)^{\frac{d}{2}}} e^{-\frac{(\xi - \mathbf{u})^2}{2c_s^2}} \qquad (2)$$

where ***u*** is the average velocity of the particles, c_s the speed of sound, and *d=2* (two-dimensional space).

Lattice Boltzmann Algorithm (Cont.)

- A Taylor-expansion of the function f^{eq} leads to:

$$f_i^{eq} = \rho w_d \left\{1 + 3\frac{\hat{e}_i \cdot \boldsymbol{v}}{c^2} + \frac{9}{2}\frac{(\hat{e}_i \cdot \boldsymbol{v})^2}{c^4} - \frac{9}{2}\frac{v^2}{c^2}\right\} \quad (3)$$

where w_d are weight factors for each direction. Direction $\hat{e}_i$ and corresponding value of w_i are {0} 4/9; {1, 2, 3, 4} 1/9; {5, 6, 7, 8} 1/36.

- This model is referred as the **D2Q9 Lattice**.

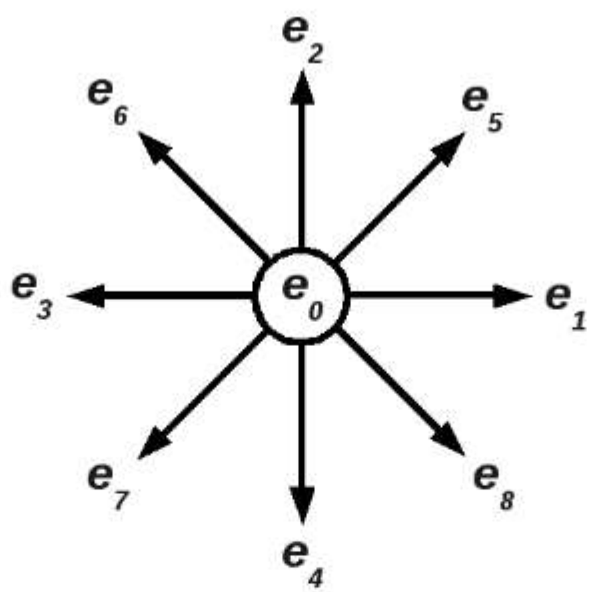
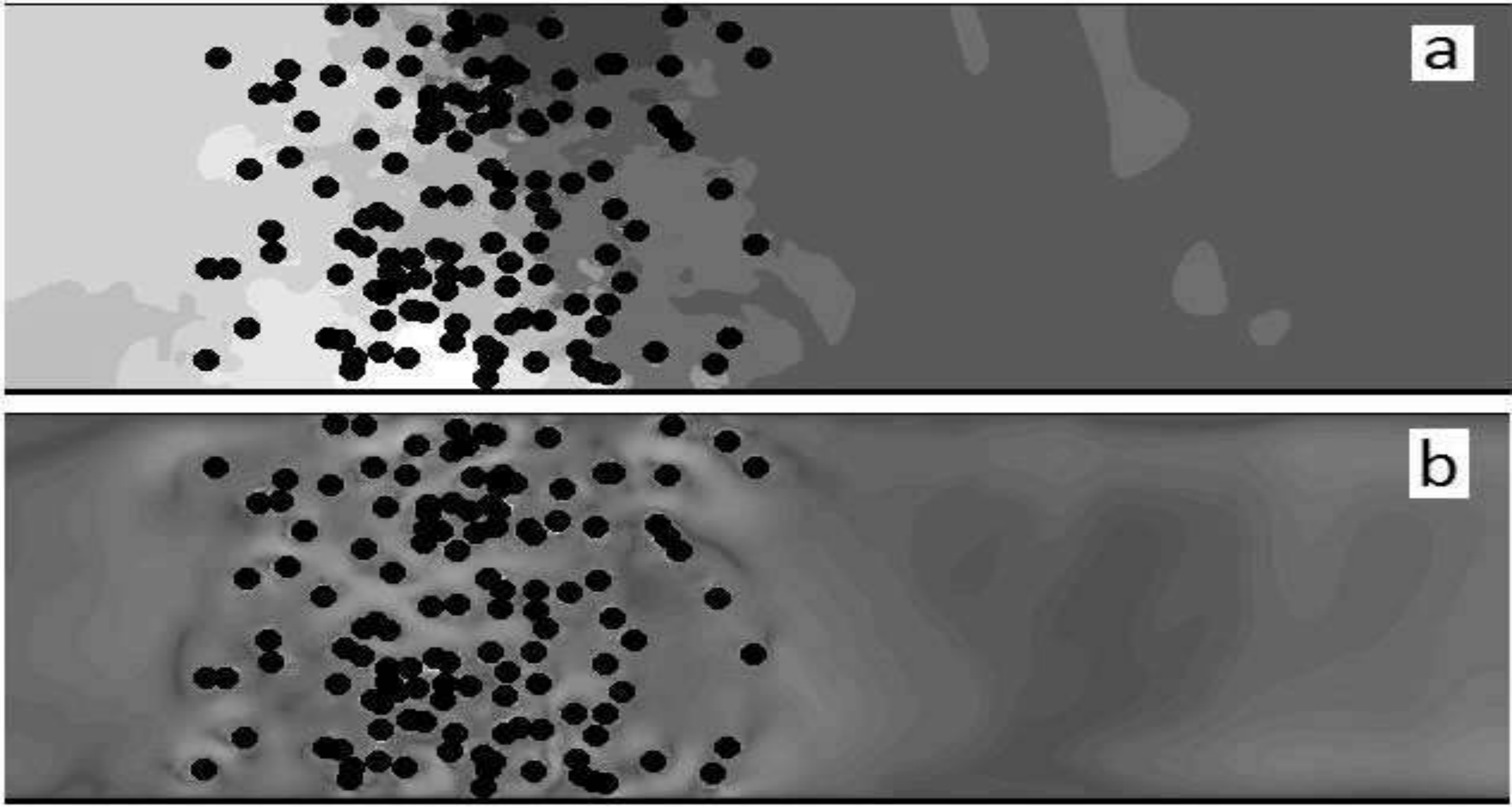


Figure 2

RESULTS

Figure 3



- Images of iso-pressure (a), and iso-velocity levels.

Values of pressure and velocity corresponds to gray levels from darker (low) to lighter (high).

RESULTS (Cont.)

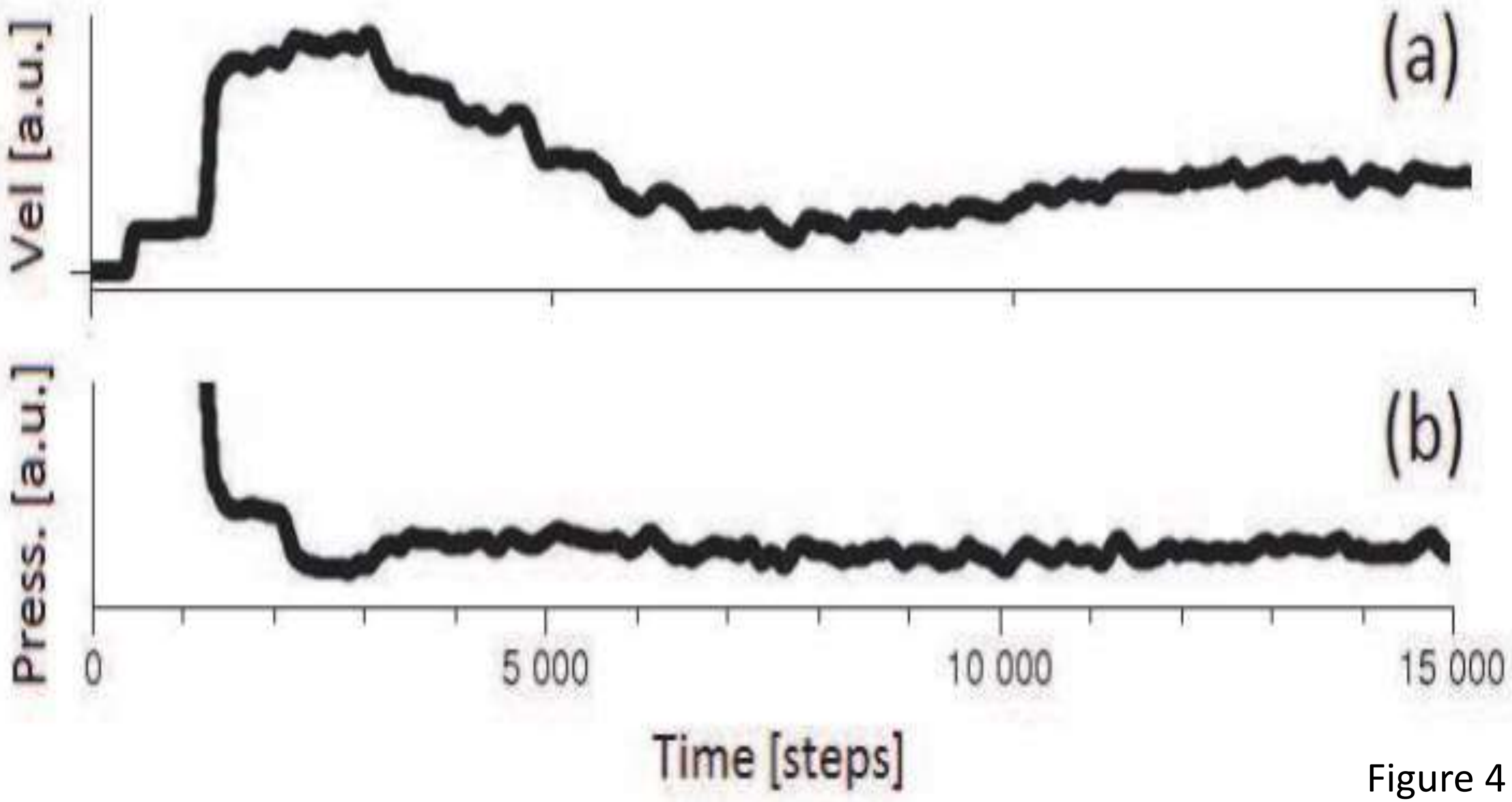


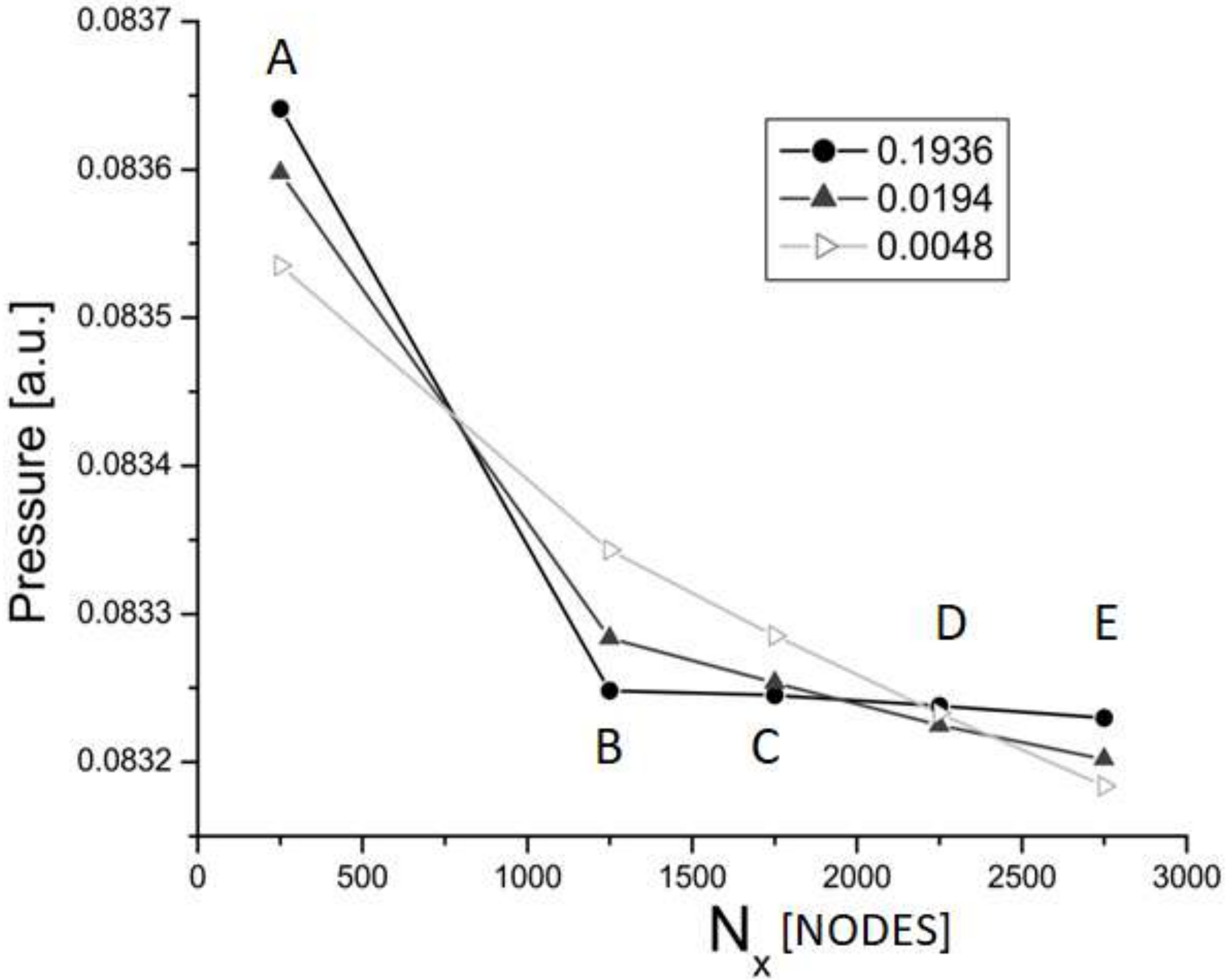
Figure 4

- Temporal evolution of the velocity (a), and pressure (b) at Point-E in Fig. 1.
- The high initial pressure variations are due to **initial conditions**.
- After transients, the pressure is stabilized, only ripples remain due to random disturbance.
- The long period oscillations of velocity are due to **finite size** of the modeling box.

RESULTS (Cont.)

- Pressure drop measured at points A, B, C, D, and E of figure 1.
- The obstacles strip covers from points A to B; the pressure drop between these two points is about 0.00030 [au]. However out of the strip, the pressure drops only 0.0005 [au].
- Each curve corresponds to a different level of effective area of the obstacle.

Figure 5



MAIN RESULT

- It was possible to measure the pressure drop (up to 30%) through a dynamic obstacle size (of an averaged 20% of the strip effective-area).

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Gracias