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Modeling the droplet impact on the solid obstacle of various shapes

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This paper deals with the modeling of the phenomenon of a droplet hitting an obstacle. The numerical model of the multiphase flow is based on the Navier-Stokes differential equations and the finite volume method. During the numerical analysis, the volume of fluid (VoF) method was used as a free surface modeling technique. Various shapes of the analyzed solid obstacles were considered in the numerical model. Two cases of multiphase flows with different surface tensions were analyzed: water-air and gasoil-air. The results were presented in the form of volumetric fraction graphs.

Conservation laws of multiphase fluid flow include the following equations:

$$\frac{dq}{dt} = -q(\nabla \cdot \mathbf{u}_1),$$

$$\frac{d(1-q)}{dt} = -(1-q)(\nabla \cdot \mathbf{u}_2),$$

where: q denotes the volume fraction of the sharp/dispersed phase taking values from 0 to 1.

The mathematical model of the droplet multiphase flow falling in horizontal tube presented in this work is based on the solution of the following differential equations:

- mass conservation:

$$\frac{\partial}{\partial t}\rho_q + \nabla \cdot \left(\rho_q \mathbf{u}_q\right) = 0,$$

- momentum conservation:

$$\frac{\partial}{\partial t}\left(\rho_q \mathbf{u}_q\right) + \nabla \cdot \left(\rho_q \mathbf{u}_q \mathbf{u}_q\right) = -\nabla p_q + \nabla \cdot \boldsymbol{\tau}_q + \mathbf{F}_q,$$

- energy conservation:

$$\frac{\partial}{\partial t}\left(\rho_q E_q\right) + \nabla \cdot \left(\rho_q \mathbf{u}_q E_q\right) = -\nabla \cdot \left(\mathbf{u}_q p_q\right) + \nabla \cdot \left(\mathbf{u}_q \cdot \boldsymbol{\tau}_q\right) + \mathbf{u}_q \cdot \mathbf{F}_q - \nabla \cdot \mathbf{J}_{iq} + J_{Eq},$$

where: ρ is a density of sharp/dispersed phase q, $\mathbf{u}_q$ is a velocity of flow, p_q is a pressure, $\boldsymbol{\tau}_q$ is a deviatoric stress tensor, E_q is a total energy per unit, $\mathbf{F}_q$ is an external force tensor, $\mathbf{J}_{iq}$ is a heat flux in q-phase and J_{Eq} is a heat source.

In the volume of fluid model, the interface between the analyzed phases is also being tracked. This is achievable by solving the following equation:

$$\frac{\partial q}{\partial t} + \nabla \cdot \left(q\mathbf{u}\right) = 0.$$

In the volume of fluid model, the interface between the analyzed phases is also being tracked. This is achievable by solving the following equation:

$$\sum_{i=1}^{n} q_i = 1.$$

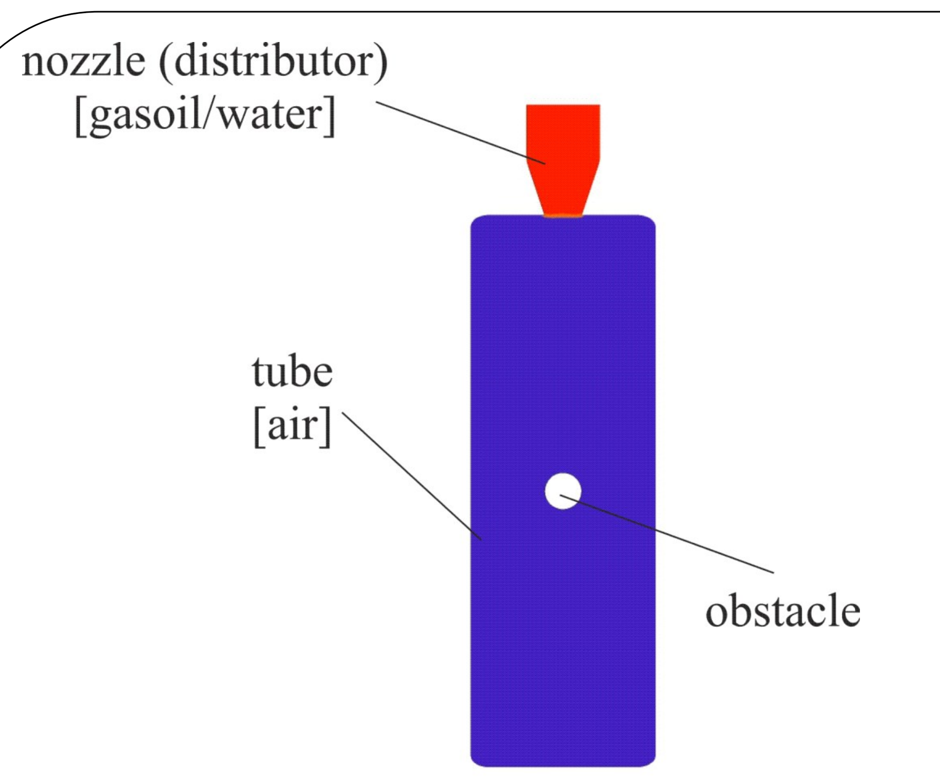

Fig. 1. Phase distribution in analyzed case

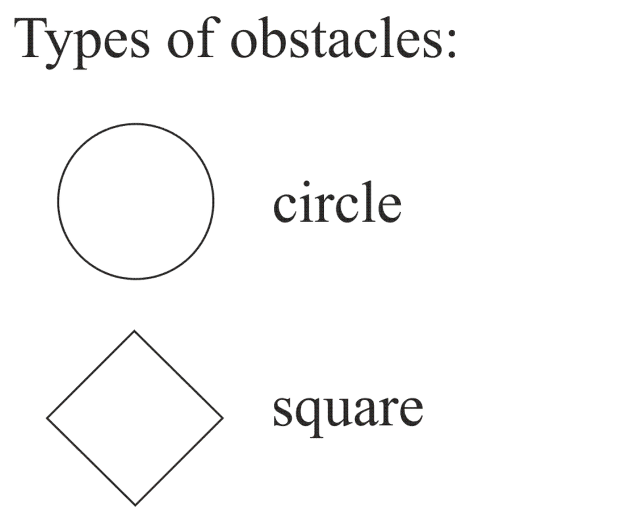

Fig. 2. Shapes of analyzed obstacles

Tab. 1. Mechanical parameters of the phases.

Phase	Density ρ [kg/m³]	Viscosity μ [kg/m·s]
Gasoil	830	3.3e-03
Water	998	1.0e-03
Air	1.23	1.79e-05

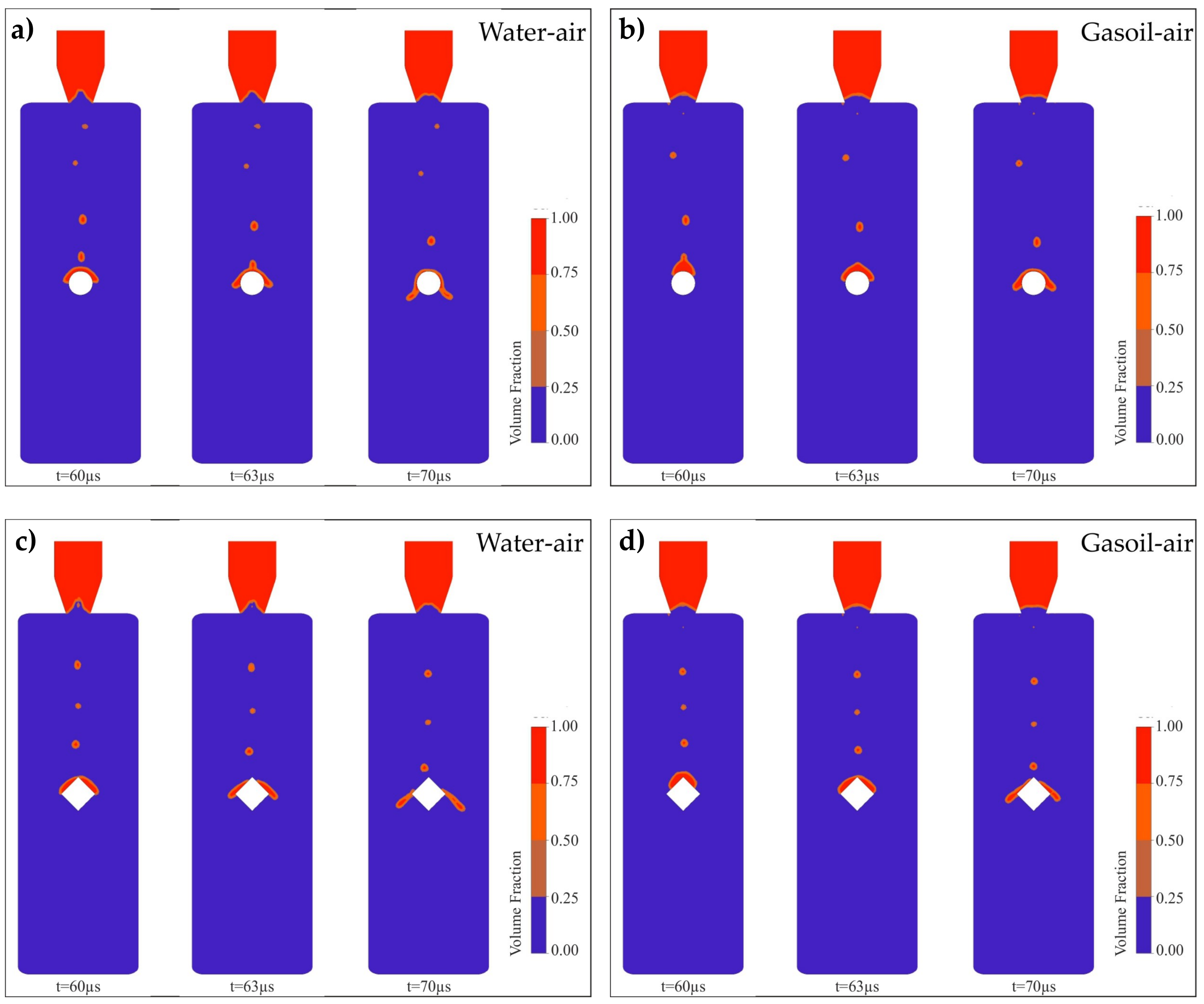

Fig. 3. Results of the droplet impact on circle (a-b) and square (c-d) obstacle for analyzed phases (water-air and gasoil-air)

The influence of the density and viscosity of the fluid upon hitting an obstacle of various shapes was analyzed. The simulation tests were run for 100µs. The simulation model took into account the surface tensions of the analyzed fluids, which was respectively: 0.073N / m for water-air case and 0.036N / m for gasoil-air example.

Comparing the obtained results, one can notice large differences during the collision of the droplet with an obstacle. During the collision of the drop with an obstacle, the circular one can be more symmetrical for both phases than in the case of a square obstacle. The square obstacle also causes a greater drop spread in the horizontal direction.

Acknowledgments

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