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Numerical simulation of the submerged hot jet propagation in a bounded domain with obstacles

The paper is devoted to numerical simulation of heat transfer by a hot liquid jet in a bounded domain with obstacles. Various options for choosing the size, shape and location of obstacles and their influence on the process of heat propagation and heating of the boundary are considered. The dependencies of the temperature at the obstacles on time and the flow regime are obtained.

Key words: *partial differential equations, numerical simulation, heat and mass transfer in liquids, applications in medicine.*

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In recent years, methods of laser-induced thermocoagulation of cysts and other neoplasms filled with biological fluids have become widespread [1, 2]. An important component of these procedures is the heat transfer by the fluid from the source to the inner surface of the cavity. Wherein, the distribution of heat is irregular, especially in areas of complex shape with internal obstacles, which can lead to local overheating and internal burns. For a better understanding of the heat transfer in these procedures, numerical simulation of the hot jet propagation in a bounded domain with obstacles was carried out for various options for choosing obstacles and a heat source.

The non-stationary Navier-Stokes equations of a viscous incompressible fluid and the convection-diffusion equation for temperature were used as a mathematical model. The jet of hot fluid resulting from boiling at the tip of the laser fiber was specified by local forces acting on the fluid and a heat source, the choice of which was based on experimental data. Different options for the jet description made it possible to simulate flows corresponding to different laser powers. The initial-boundary value problem for the nonlinear system of partial differential equations was solved by the finite element method using the free software package FreeFEM.

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In laser therapy of cysts, the main goal is to heat the boundary and obstacles to the temperature of protein coagulation. An analysis of numerical results showed a different rate of temperature increase. Obstacles and a part of the boundary away from the source heat up much more slowly compared to obstacles located near the source.

In this case, three main configurations were identified that form fundamentally different flow regimes. The first option corresponds to large obstacles that block the propagation paths of a hot fluid jet, which leads to the formation of a local hot vortex that heats only the obstacles in contact with it.

Fig. 1 shows the average temperature values (in degrees Celsius) increasing with time on the boundary and some obstacles. Here we use the following designations: 0 — the domain boundary; 1 — an obstacle close to the heat source that does not come into contact with the hot vortex; 2 — a close obstacle in contact with the vortex; 3 — an obstacle located far from the heat source. The parameters of the jet correspond to a laser power of 3 W. It can be seen from the graphs that the obstacle in contact with the vortex heats up in a few seconds to the protein coagulation temperature, while the temperature of the boundary and the remote obstacles changes very slowly. If the hot vortex comes into contact with a part of the boundary, then this part also heats up very quickly, and further continuation of the procedure can lead to internal burns.

In the second configuration, a small number of small obstacles cannot stop the jet propagation and do not have a large effect on heat transfer. This situation is similar to the case without obstacles. In the third configuration, a large number of small obstacles significantly slows down the heating process of the entire domain and its boundaries.

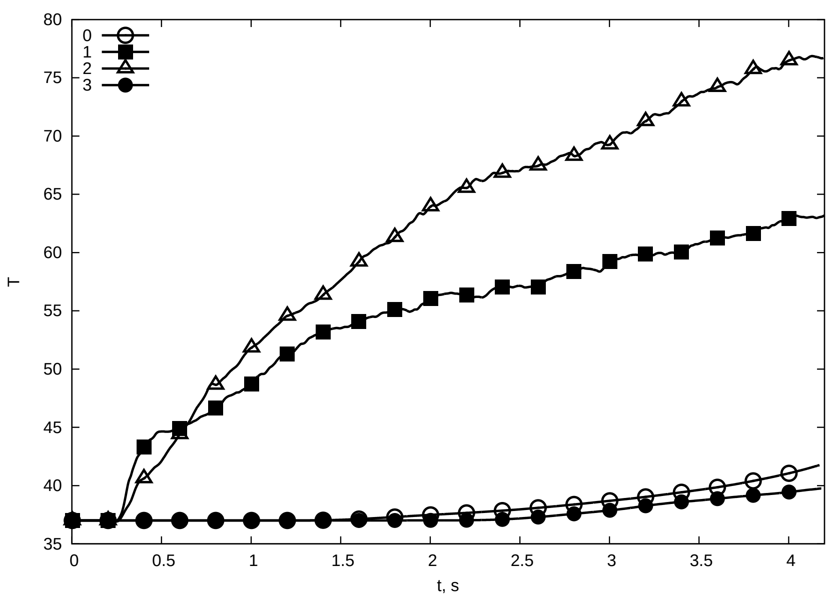

Fig. 1: Average temperature on the boundary and obstacles

The obtained numerical results clearly show the need to move the source of the hot jet during this procedure. Based on the calculations performed for all considered configurations with different choices of obstacles, we proposed options for a phased displacement over the domain and a change in the angle of the laser fiber to achieve uniform heating of the obstacles and the boundary.

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АННОТАЦИЯ

Статья посвящена численному моделированию переноса тепла струей горячей жидкости в ограниченной области с препятствиями. Рассмотрены различные варианты выбора размера, формы и расположения препятствий и их влияние на процесс распространения тепла и нагрев границы области. Получены зависимости температуры на границе препятствий от времени и режима течения.

Ключевые слова: *уравнения в частных производных, численное моделирование, тепломассоперенос в жидкости, приложения в медицине.*