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Numerical simulation of the heat transfer process in biological tissues during laser heating

The paper presents the results of numerical simulation of the process of heat propagation in vessels and adjacent biological tissues as a result of exposure to a hot jet induced by laser radiation. The results of the work allow us to make an estimate for the jet velocity at which uniform heating of tissues to an acceptable temperature is possible, which is of great practical importance.

Key words: *lasers, heat conduction, submerged jet, biological tissue.*

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Problem Statement

Simulation of the formation of hot jets in the process of laser heating is one of the interesting problem that allows one to evaluate the effect of a propagating temperature field on tissue heating. It is known that the optimal heating temperature leading to protein coagulation is $70°C$. The present study shows the method for heating a round area of radius $R = 1$ cm, consisting of sections with biological tissue, between which there is a biological fluid. Since a submerged jet with a temperature of $100°C$ [1] is formed at the tip of the waveguide during bubble collapse, it is necessary to find the optimal parameters of the submerged jet velocity and the intervals between the emerging bubbles, which will allow creating conditions for uniform heating of the area under study up to a temperature of $70°C$. The location and size of the tissue sections are set in such a way that the average size of the interstitial space is 1 mm. The properties of the interstitial substance and tissue correspond to water. Adhesion conditions and ideal heat transfer on the contact surfaces are set between the tissue and the interstitial substance. On the outer surface of the computational domain, the no-slip conditions and the outlet heat flux of 100 W/m^2 are set. The waveguide region is defined by a cut out rectangle in

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the lower part of the computational region with a width of 0.4 mm. A temperature of $100°C$ is set on the upper part of the waveguide. The initial temperature of the tissue and interstitial substance is $36.4°C$.

Results

The problem was solved in a two-dimensional formulation using the finite volume method within the framework of the Ansys Fluent 2021 package. The fluid dynamics model is described by the continuity equations, the Navier-Stokes equations and the k-epsilon standard turbulence model. The system of equations is closed by the heat equation and the boundary conditions presented in the previous chapter. As a result of calculations, it was found that uniform heating of biological tissue occurs at a flooded jet velocity $v = 100\ m/s$. In this case, the jet action interval is 0.001 s. After that, within 0.1 s, the average temperature of the biological tissue reaches the value of $70°C$. Fig. 1 shows the temperature distributions at different times.

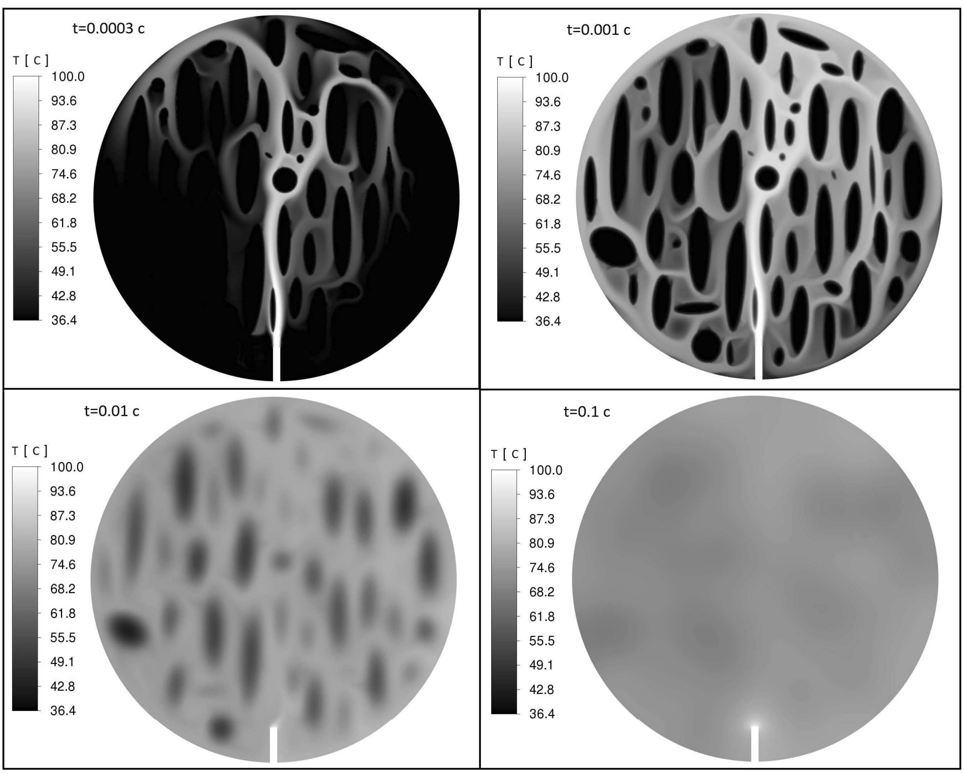

Fig. 1: Temperature distributions at different times.

Conclusion

The dynamics of temperature field propagation in biological tissues subjected to rapid heating of a hot submerged jet is calculated. It is shown that with a short exposure to a hot jet, the process of uniform heating of tissues to a given temperature is possible.

References

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АННОТАЦИЯ

В работе представлены результаты численного моделирования процесса распространения тепла в сосудах и прилегающих к ним биологических тканях в результате воздействия горячей струи, индуцированной лазерным излучением. Результаты работы позволяют сделать оценку для скорости струи, при которой возможен равномерный разогрев тканей до допустимой температуры, что имеет большое практическое значение.

Ключевые слова: *лазеры, теплопроводность, затопленная струя, биологическая ткань.*