Modelling of Heat and Mass Transfer during Cryopreservation in Biological Sample Treated as Homogeneous and Porous Material with Uncertainty

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Porous materials are composed of a solid matrix and pores containing a fluid. One of the key properties of a porous medium is porosity, defined as the ratio of the pore volume to the total volume of the material. Biological tissues consist of cells separated by pores through which, for example, nutrients are transported. Therefore, it is appropriate to model them not only as homogeneous materials, but also as porous ones [1].

Biological systems can be analysed in the context of various phenomena, including cryopreservation, which involves storing biological material at low temperatures. The mathematical model considers, among other things, heat and mass transfer [2]. Thermal processes are governed by heat conduction and blood perfusion (blood convection), while mass transfer occurs as a result of diffusion associated with the movement of cryoprotectants (CPAs) or nutrients through the pores [1].

Heat transfer is described by the Fourier equation, whereas mass transfer is governed by a diffusion equation based on Fick's law. The phenomena are coupled, as the diffusion coefficient appearing in the mass transfer equation depends on temperature. The diffusion coefficient is defined in three different ways: (1) using the Einstein–Stokes equation, (2) the Arrhenius expression, and (3) a formulation accounting for the porous structure of the material. The first two approaches treat the biological sample as homogeneous, whereas the third one accounts for its porous structure [3].

Furthermore, the parameters of biological models are determined experimentally, and may therefore be subject to uncertainty. Such uncertainty can be analysed using probabilistic or non-probabilistic methods. Non-probabilistic approaches include, for example, the theory of interval numbers, defined by lower and upper bounds specifying the range of possible values [4].

This article presents a mathematical and numerical model of coupled heat and mass transfer during the cryopreservation of biological material. The tissue is modelled as both a homogeneous and a porous medium; in the former case, uncertain parameters are introduced using interval numbers.

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