Numerical Modelling of Transient Heat Transfer in an Axisymmetric Cylindrical Container with Phase Change Materials

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The paper concerns numerical modelling of transient heat transfer in a cylindrical container used for vaccine transport, with the application of phase change materials (PCMs). The considered system consists of a multilayer structure including an insulating layer, an ice domain and an additional PCM layer. The role of the PCM is to stabilize temperature and prevent vaccine freezing. Due to the geometry, the problem is formulated in an axisymmetric coordinate system.

The mathematical model is based on the heat conduction equation in cylindrical coordinates

$$c\rho \frac{\partial T(r,z,t)}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(\lambda r \frac{\partial T(r,z,t)}{\partial r}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial T(r,z,t)}{\partial z}\right). \tag{1}$$

Thermophysical parameters depend on temperature, and the phase change process is described using the apparent heat capacity approach. Heat transfer in the domain is assumed to be conductive, while appropriate boundary conditions, including convection and radiation, are imposed on the outer surfaces.

In contrast to the reference model based on the finite element method [1], the present study applies the finite difference method (FDM), formulated directly in cylindrical coordinates [2]. This formulation enables efficient numerical implementation and reduces computational cost.

Calculations are performed for selected geometric parameters, including the thickness of insulation, ice and PCM layers. The analysis focuses on the influence of the additional PCM layer on temperature distribution in the storage region, particularly in the range required for safe vaccine transport (2–8°C). The numerical results are analysed with respect to data reported in the literature [1]. The obtained agreement confirms the correctness of the model and the suitability of the FDM approach for this type of problem.

The results show that the application of an additional PCM layer significantly improves thermal conditions and extends the safe storage time. The developed model can be used in further analysis and optimization of thermal systems applied in cold chain transport.

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