Heat and Mass Transfer Modelling During Freezing of Foodstuffs

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Abstract

The objective of this study is to develop a mathematical model dedicated to the determination of the weight loss and the freezing rate during freezing of unwrapped foodstuffs in a very cold environment. Freezing is a preservation method widely used in the food industry. Frozen foods can be obtained by several techniques and among them, cryogenic freezing is useful for increasing the freezing rate thanks to low temperatures. A rapid reduction of the surface temperature of unwrapped food results in a rapid reduction of partial vapour pressure at the surface of food. Hence in case of rapid freezing, a reduction of the mass loss by evaporation is expected in comparison with slow freezing conditions. For non porous food, water evaporates from the surface and is replaced by water diffusing from the centre to the surface until freezing occurs. Thereafter there is no significant water diffusion inside the food and sublimation can occur at surface.
A mathematical model is built in order to compare two freezing processes applied to methylcellulose gel; the first one uses nitrogen gas at -80°C and the other one is the classical method using cold air. The model for conductive heat transfer is based on Fourier equations:

In order to take into account the phase change, the model includes thermophysical properties that are temperature dependant. The apparent specific heat capacity Cp(T) is deduced from the enthalpy curve obtained by DSC and the Maxwell model is used for the thermal conductivity k. The apparent specific heat capacity has to be corrected and the Schwartzberg model is used to include ice formation. The numerical study reveals that the time step has to be chosen carefully in order to preserve the heat balance during the simulation of freezing.
The moisture loss by evaporation or sublimation is described by means of Fick's law. Moisture flux inside the food consists of liquid diffusion and we consider that the ice is stationary. The value of the effective diffusivity is obtained from literature review. Numerical results indicate that the heat loss due to evaporation or sublimation can represent 10% of the heat loss due to convection during cryogenic freezing. Comparisons are made with experimental data. They confirm that the weight loss is reduced if very low temperatures are used and that the heat transfer coefficient has less influence than the outside temperature.