Describing 3D turbulent heat convection and freezing of solid foods by computational modelling: Energy, exergy and quality food issues for salmon and beef

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Demands for high quality and healthy foods requires careful processing in which transport phenomena play a key role in achieving the expected quality. Therefore, the objective of this work was to characterize the transient turbulent convective heat transfer and fluid mechanics in air inside a freezer around pieces of beef and salmon, along the unsteady heat conduction with water freezing in the foods. The method incorporated a mathematical conjugate model with temperature dependent apparent specific heat that included the liquid-solid phase change of the water content in the foods, with properties varying with temperature. Continuity, linear momentum, energy, turbulent kinetic energy and rate of energy dissipation equations were solved by numerical simulations with an in-house SIMPLEC finite volume code implemented using non-uniform staggered grids. Precise numerical results for predicting the freezing rate and heat transfer were calculated by second order accurate temperature gradients. Additionally, a local exergy destruction analysis quantified the irreversibility produced by viscous dissipation and heat transfer during freezing. The effects of position and number of blocks of salmon in a freezer on cooling rate were investigated using computational modelling. Evolution of velocity and temperature distributions in air, and temperature, cooling rate and Nusselt number (Nu) in the meat were among the main results obtained. Accurate temperature measurement by thin thermocouples in beef were in qualitative and quantitative agreement with the 3D numerical simulations. The highest cooling rate was for the food at the lower corner, and the lowest when was located at the center of the freezer. The conclusions indicates that the turbulent k-e HH model describes properly the airflow velocity and temperature, obtaining a Nu 64% higher than the laminar flow model. The three-dimensional model achieves the best adjustment to the available experimental results, reaching a Nu 28% higher than the 2D model. The entropy analysis determined a total exergy destroyed of 187 (W), mainly during the first hour of the freezing process. Finally, the conjugate computational model related the freezing rate with the luminosity predicting the changes in the color of the pieces of salmon, that is a relevant quality factor for this healthy food.