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PREDICTION OF FREEZING AND THAWING TIMES FOR FOODS

A thesis presented in partial fulfilment of the
requirements for the degree of Doctor of
Philosophy in Biotechnology at
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ABSTRACT

A study of methods to predict the freezing and thawing times of both regular and irregular shaped foods was made.

Experimental thawing data for foods found in the literature, were limited in value because the experimental conditions were not sufficiently accurately measured, described and controlled to allow meaningful testing of thawing time prediction methods to be made. A comprehensive set of 182 experimental measurements of thawing time were made over a wide range of conditions using regular shapes made of Tylose, a food analogue, and of minced lean beef. Freezing and thawing experiments for irregular shapes were also carried out because of the paucity of published experimental data. Using twelve different two- and three-dimensional irregular shaped objects 115 experimental freezing and thawing runs were conducted. Combining experimental results with reliable published experimental data for freezing, a data set comprising 593 experiments was established against which prediction methods were tested.

The partial differential equations that model the actual physical process of heat conduction during freezing and thawing can be solved by the finite difference and finite element methods. Testing of the finite element method has not been extensive, particularly for three-dimensional shapes. Therefore a general formulation of the finite element method for one-, two- and three-dimensional shapes was made and implemented. Both numerical methods accurately predicted freezing and thawing times for regular shapes. Sufficiently small spatial and time step intervals could be used so that errors arising from the implementation of the methods were negligible compared with experimental and thermal property data uncertainties. Guidelines were established to choose space and time grids in application of the finite element method for irregular shapes. Adherence to these guidelines ensured that prediction method error was insignificant. A simplified finite element method was formulated and implemented. It had lower computation costs but was less accurate than the general formulation.

No accurate, general, but simple method for predicting thawing times was found in the literature. Four possible approaches for a generally applicable, empirical prediction formula were investigated. Each could be used to predict experimental data for simple shapes to within ±11.0% at the 95% level of confidence. This accuracy was equivalent to that displayed by similar formulae for freezing time prediction, and was only slightly inferior to the accuracy of the best numerical methods. All four methods are recommended as accurate predictors.

For multi-dimensional shapes there were two existing geometric factors used to modify slab prediction methods - the equivalent heat transfer dimensionality (EHTD) and the mean conducting path length (MCP). New empirical expressions to calculate these factors for regular shapes were developed that were both more accurate and more widely applicable than the previous versions. Principles by which EHTD and MCP could be determined accurately for any two- or three-dimensional shapes were established. The effect of the first and second dimension were accurately predicted but lack of sufficient data (due to high data collection costs) prevented accurate modelling of the effect of the third dimension for some irregular shapes.

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