PREDICTION OF CHILLING TIMES OF FOODS

SUBJECT TO

BOTH CONVECTIVE AND EVAPORATIVE COOLING

AT THE PRODUCT SURFACE

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ABSTRACT

No published chilling time prediction method which covers a wide range of practical conditions, and which can be applied using only simple algebraic calculations for chilling with evaporation at the product surface has been proven accurate. The objective of the present work was to develop and test a simple chilling time prediction method with wide application for situations where significant evaporation as well as convective cooling occurs from the product surface.

A numerical method (finite differences) was used to simulate convection and evaporation at the product surface in cooling of solid products of simple shape (infinite slab, infinite cylinder, and sphere) with constant surface water activity. Semi-log plots relating temperature change to be accomplished to time were linearised by appropriate scale transformations based on the Lewis relationship. The effect of evaporation on cooling rate was measured by considering the slope and intercept of such plots, and comparing these to the slope and intercept that would arise in convection-only cooling. The enhancement of cooling rate due to the evaporative effect depended on six parameters; initial product temperature, cooling medium temperature, Biot number, relative humidity, product shape factor, and surface water activity.

Four simple algebraic equations were curved-fitted to the numerically simulated data for predicting temperature-time profiles at centre and mass average positions in the product. The numerically generated results and the simple algebraic equations agreed well with a mean difference close to 0 % for all three shapes, and 95% confidence bounds of about ±3 % for the infinite cylinder, and ±5 % for the infinite slab and the sphere geometries.

To test the simple models, chilling experiments were conducted in a controlled air flow tunnel across a range of conditions likely to occur in industrial practice. Trials were conducted using infinite cylinders of a food analogue as an idealised product (with saturated salt solutions percolating over a wet cloth on the product surface to maintain constant surface water activity), and carrots (both peeled and unpeeled) as examples of real food products.

Measured centre temperatures for both the idealised products and peeled carrots were predicted by the proposed method, assuming a constant surface water activity, within a range of differences which was almost totally explainable by experimental uncertainty. For unpeeled carrots, predictions mode using three different surface water activities in the model (one to represent the initial condition, one to represent the active chilling phase, and one to represent the quasi-equilibrium state at the end of chilling) agreed sufficiently well with experimental centre temperature data for the lack of fit to be largely attributable to experimental uncertainty. No experimental verification for prediction of mass-average temperatures was attempted.

The proposed method is recommended for predicting chilling times of food products of infinite slab, infinite cylinder or sphere shapes, across a wide range of commonly occurring chilling conditions provided the product has constant surface water activity. The establishment of bounds on a theoretical basis for limiting the ranges in which surface water activity values are selected for making predictions for products with non-constant surface water activity is proposed, and some guidance on application of these bounds established. Further work to refine the use of these bounds for a range of food products, to consider a wider range of shapes, to test the ability of the proposed method to predict mass-average temperatures is recommended.

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