MODELING HEAT TRANSFER IN BUTTER PRODUCTS

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ABSTRACT

Butter keeping quality and pallet physical stability during transport and storage are dependent on the temperature distribution through the product. Understanding these temperature changes are of vital importance for the dairy industry with regard to butter manufacture, storage and shipping.

Three dimensional mathematical models of heat transfer were developed to predict thawing and freezing in butter products. These models require accurate thermophysical data as an input. Specific heat capacity and enthalpy of butter with different composition was measured using Differential Scanning Calorimetry. The specific heat capacity of butter differs for cooling and heating operations due to significant supercooling and delayed crystallization of the fat fraction of butter at temperatures well below the equilibrium phase change temperature during cooling. This reduces the heat capacity for cooling relative to that for heating.

Thawing of individual blocks of butter was accurately predicted by the conduction only model (no mass transfer limitations) with equilibrium thermal properties giving accurate predictions when the butter was completely frozen before thawing. For partially frozen butter the conduction model with the measured temperature dependent specific heat capacity data for unfrozen butter including melting of some of the fat fraction gave accurate predictions.

For freezing it was observed that water in the butter supercools many degrees below its initial freezing point before freezing due to its water in oil structure. Experiments suggested that during freezing release of latent heat observed as a temperature rebound is controlled as much by the rate of crystallisation of water in each of the water droplets as by the rate of heat transfer. A conduction only model including water crystallization kinetics based on the Avrami Model predicted freezing in butter successfully. Simple models with equilibrium thermal properties and nucleation only kinetics (based on homogenous nucleation theory) or the sensible heat only model (no release of latent heat) gave poor predictions.

The models for individual blocks were extended to predict heat transfer in butter pallets. A butter pallet contains product, packaging material and the air entrapped between the packaging and butter cartons. Measurements were made for freezing and thawing of full and half pallets at a commercial storage facility and in the University laboratory. Thawing and freezing in wrapped tightly stacked

pallets was predicted accurately by the conduction only model with effective thermal properties (incorporating butter, packaging and air) estimated by the parallel model.

For unwrapped tightly stacked or loosely stacked pallets there is potential for air flow between the adjacent cartons of butter. An alternative approach was developed which consisted of modeling the pallet on block by block basis using effective heat transfer coefficients for each surface. Different heat transfer coefficients were used on different faces of the blocks depending on the location of the block in the pallet. This approach gave good predictions for both unwrapped tightly stacked and loosely stacked pallets using the estimated effective heat transfer coefficients from the measured data. Further experimental and/or modelling work is required in order to develop guidelines for estimating effective heat transfer coefficient values for internal block face for industrial scenarios.

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