THERMAL PROPERTIES OF FROZEN FOODS

Introduction

The food product properties of interest when considering the freezing process include density, specific heat, thermal conductivity, enthalpy, and latent heat. These properties must be considered in the estimation of the refrigeration capacity for the freezing system and the computation of freezing times needed to assure adequate residence times. The approach to prediction of property magnitudes during the freezing process depends directly on the relationship between unfrozen water fraction and temperature.

It is important to study thermal properties of foods because they affect the design of food processing equipment. The food products undergo changes in composition during such process as freezing, evaporation and dehydration. There are different methods available to measure the thermal properties of food, but the available data differ depending on the method used. The important thermal properties of food are as follows:

11.2 Density

The density is mass per unit volume. Usually the density is expressed in grams per mL or cc. Mathematically a "per" statement is translated as a division. cc is a cubic centimeter and is equal to a ml Therefore,

The influence of freezing on food product density is relatively small but a dramatic change does occur at and just below the initial freezing temperature. This change can be predicted by the following equation, as discussed by Heldman (2001):

$$\rho = 1/ \sum (m_{si} / \rho_{si})$$

Specific Heat

A measure of the heat required to raise the temperature of a substance. When the heat ΔQ is added to a body of mass m, raising its temperature by ΔT, the ratio C given in Eq. (1) is defined as the heat capacity of the body.

$$C_p = \Delta Q/ \Delta T$$

The specific heat capacity of a food product can be predicted, based on product composition and the specific heat capacity of individual product components. The following expression was proposed:

$$Cp = \sum (C_{psi} . m_{si})$$

where each factor on the right-side of the equation is the product of the mass fraction of a product component and the specific heat capacity of that component. The specific heat values for product components were estimated by Choi and Okos (1986). The above equation can be used to predict the specific heat capacity of product solids by removing the term for the water fraction. These specific heat magnitudes for the product solids can be used in the prediction of product enthalpy and apparent specific heat.

$C_p = 4.180\ X_w + 1.711\ X_p + 1.98\ X_f + 1.547\ X_c + 0/908\ X_a$, ; kJ/kg^{0}C ....Cho's and Oko's Model

Where, X_w: water fraction

X_p: Protein fraction

X_f: Fat fraction

$X_{c:}$ Carbohydrate fraction

$X_{A:}$ Ash fraction

Thermal Conductivity

Thermal conductivity (λ) is the intrinsic property of a material which relates its ability to conduct heat. Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole. Conduction takes place when a temperature gradient exists in a solid (or stationary fluid) medium. Conductive heat flow occurs in the direction of decreasing temperature because higher temperature equates to higher molecular energy or more molecular movement. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide.

Thermal conductivity is defined as the quantity of heat (Q) transmitted through a unit thickness (L) in a direction normal to a surface of unit area (A) due to a unit temperature gradient (ΔT) under steady state conditions and when the heat transfer is dependent only on the temperature gradient. In equation form this becomes the following:

Thermal Conductivity = heat × distance / (area × temperature gradient)

$$\lambda = Q \times L / (A \times \Delta T)$$

The thermal conductivity magnitudes of most food products are a function of water content and the physical structure of the product. Many models suggested for prediction of thermal conductivity are based on moisture content and do not consider structural orientation. The Choi's and Oko's Model for prediction of thermal conductivity is as follows.

$K = 0.58\ X_w + 0.155\ X_p + 0.25\ X_c + 0.16\ X_f + 0.135\ X_a$, W/m ºK ....Cho's and Oko's Model

Where, X_w: water fraction

X_p: Protein fraction

X_f: Fat fraction

$X_{c:}$ Carbohydrate fraction

$X_{a:}$ Ash fraction

Thermal Diffusivity

A measure of the rate at which a temperature disturbance at one point in a body travels to another point. It is expressed by the relationship K/dC_p, where K is the coefficient of thermal conductivity, d is the density, and C_p is the specific heat at constant pressure. Very little thermal diffusivity data are available, but it can be determined using relationship of specific heat, thermal conductivity and mass density of the food product.

Freezing Point Depresssion

Probably one of the more reveling properties of water in food is the freezing point depression. Since all food products contain relatively large amounts of moisture or water in which various solutes are present, the actual or initial freezing point of water in the product will be depressed to some level below that expected for pure water.

The magnitude of this freezing point depression becomes a direct function of the molecular weight and concentration of the solute in the food product and in solution in the water.

Thermodynamics of Food Freezing

Freezing is one the more common processes for the preservation of foods. It is well known that lowering the temp reduces the activity of microorganisms and enzyme systems, thus preventing deterioration of the food products. In addition to the influence of temp reduction on m.o. and enzymes, crystallization of the water in the product tends to reduce the amount of liquid water in the system and inhibit microbial growth or enzyme activity in the secondary action.

The engineering aspects of food freezing include several interesting areas. In order to design a refrigeration system that will serve a food freezing process, some indication of the refrigeration requirements or enthalpy change which occurs during product freezing is required. This aspect is related to the type of product being frozen. The second aspect of food freezing that is closely related to engineering is the rate at which freezing progresses. This aspect is related to the refrigeration requirement, but the temperature difference existing between the product and freezing medium are also of significance. The rate of freezing is also closely related to product properties and quality. Product properties resulting from very rapid freezing are significantly different from those obtained by slow freezing. This difference is dependent primarily on the manner in which ice is formed within the product structure. In addition, the rate of freezing will establish the rate of production for a particular food- freezing operation. For this purpose the most rapid rate of freezing is desirable provided that product quality is not sacrifice.

Examples

Example 11.1

A formulated food product contains the following components – water 80%, protein 2%, carbohydrate 17%, fat 0.1% and ash 0.9%. Predict the specific heat in W/kg K using Choi's and Oko's model.

Solution:

$C_p = 4.180\ X_w + 1.711\ X_p + 1.98\ X_f + 1.547\ X_c + 0/908\ X_a$

$= 4.180\ (0.8) + 1.711\ (0.02) + 1.98\ (0.001) + 1.547\ (0.17) + 0.908\ (0.009)$

$= 3.651\ kJ/kg^oC$

$= 0.8726\ kCal/kg^oC$

$= 1.0147\ W/kg^oC$

Example 11.2

Calculate the thermal conductivity of milk using choi & OKOS model, if milk contains 87.5% water, 3.7% protein, 3.7% fat, 4.6% lactose and 0.5% ash at 10^0C.

Solution

$K = 0.58\ X_w + 0.155\ X_p + 0.25\ X_c + 0.16\ X_f + 0.135\ X_a$

$= 0.58\ (0.875) + 0.155\ (0.037) + 0.25\ (0.046) + 0.16\ (0.037) + 0.135\ (0.005)$

$= 0.49 + 0.005735 + 0.0115 + 0.00592 + 0.000675$

$= 0.51383$ W/m ºK

Freezing times are basic design criteria for freezing systems and represent the residence time for the food product within the freezing system required to achieve the desired level of freezing. The most widely accepted definition of freezing time is the time required to reduce the product temperature from some initial magnitude to an established final temperature at the slowest cooling location. An alternative definition changes the endpoint to the mass average enthalpy equivalent to the desired final temperature for the product. Freezing-time calculations are completed as a first step in the design of a food freezing system. The freezing time establishes the residence time for the product in the system. The final product temperature is established as the magnitude needed to maintain optimum product quality during storage. For a continuous freezing system, the resident time is dependent on the rate of product moves through the system and on the length of the system. More specific characteristics of the design will depend on the type of freezing system being considered.

Freezing Time Equation (Plank's Equation)

The most straight forward expression available for computing freezing time was derived by plank. The equation utilized, for computation purpose be derived for various geometries of product. By reference to fig. given below, the case of one-dimensional freezing of a product slab can be illustrated the three basic equations utilized in a the derivation account for the first expression is the basic heat-conduction equation for the frozen product region which has a variable thickness x as follow:

where *P* and *R* are constants that depend on product geometry (Table 13.1).

The limitations to Planck's equation for estimation of freezing times for foods are numerous and have been discussed by Heldman and Singh (1981) and Ramaswami and Tung (1981). One of the concerns is selection of a latent heat magnitude *(L)* and an appropriate value

for the thermal conductivity *(k)*. In addition, the basic equation does not account for the time required for removal of sensible heat from unfrozen product above the initial freezing temperature or for removal of frozen product sensible heat. There have been numerous attempts to modify Planck's equation or develop alternative expressions.
The modifications made in the expression by number of scientists.

Limitations of Planck's Equation

1. Use of equation requires assumption of some latent heat value and doesn't consider the gradual removal of latent heat.
2. The equation utilized only the initial freezing point and neglects the time required to remove sensible heat above the initial freezing point.
3. Constant thermal conductivity is assumed for the frozen portion. In fact thermal conductivity of the frozen region is temperature dependent and hence variable.
4. Density values for frozen foods are difficult to measure.
5. The initial and final temperature is not accounted for in the equation.

Even with these limitations, Planck's equation becomes most popular method for freezing time prediction.

Assumptions of Planck's Equation

1. Freezing starts with all water in the food unfrozen but at its freezing point and loss of sensible heat is ignored.
2. Heat transfer takes place sufficiently slowly for steady state conditions to operate.
3. The freezing front maintains a similar shape to that of the food.
4. There is single freezing point.
5. The density of food doesn't change.
6. The thermal conductivity and specific heat of the food are constant when unfrozen and then change to a different constant value when the food is frozen.

Thawing

Thawing is primarily used for frozen meats, poultry and seafood as most vegetables can be cooked without thawing. It is important to follow these guidelines to thaw safely because bacteria can multiply rapidly when left unrefrigerated for more than two hours in the so called temperature "danger zone," between 40°F - 140 °F.

How To Thaw

Here are a few safe methods to thaw frozen foods:

1. In The Refrigerator:

- Plan ahead because it takes about one day to thaw most foods.
- Place frozen food on a plate or in any container to catch the juices that may leak.
- Place in bottom of refrigerator.
- You may refreeze food that has been thawed in the refrigerator before or after cooking.
- This is the safest way to thaw meat and poultry.

2. In Cold Water:

- Put the frozen item in a watertight plastic bag.
- Submerge in cold water - cold water slows bacteria that might be growing in the thawed portions of the food.
- Make sure to change water every 30 minutes.
- Cook immediately after thawed.
- You must fully cook all foods thawed in cold water before refreezing.
- This is a faster method - takes a couple of hours depending on weight.

3. In The Microwave:

- Remove any store wrapping.
- Place in a microwave-safe container.
- Follow microwave instructions from the owner's manual.
- Cook immediately after thawed.
- You must fully cook all foods thawed in microwave before refreezing.
- This method is for immediate thawing.

Cooking Without Thawing

If you don't have enough time to thaw food, just remember, it is safe to cook foods from a frozen state — but your cooking time will be approximately 50% longer than for fully thawed foods.

Most frozen vegetables can be cooked without thawing. Cook in ½ cup or less of water, drain and then season with your favorite herbs and spices.

Note:

- Never thaw on the kitchen counter!
- Never thaw in hot water!
- Never thaw outdoors!