# Properties of Frozen Foods


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# Frozen food properties

- 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.

Liquid water at 25 C---

Temperature profile…25---24—23….12..7…2..0….

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

-The density of ice is about 0.92 **g cm**$^{-3}$ and that of water is about 1.00 **g cm**$^{-3}$ at 0 °C.

**-it is due to tetra-hedral open cage structure of ice.**

# Specific heat

- A measure of the heat required to raise the temperature by one degree of a unit mass of substance.
- When the heat $\Delta Q$ is added to a body of mass $m$, raising its temperature by $\Delta T$, 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:

$$Cp = \sum (Cpsi.\ m\ si)$$

- 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.

# Contd…

- 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.

**specific heat ($C_p$) of product= 4.180 $X_w$ + 1.711 $X_p$ + 1.98 $X_f$ + 1.547 $X_c$ + 0/908 $X_a$**

**specific heat ($C_p$) of product solids= 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

Xp: Protein fraction

$X_f$: Fat fraction

$X_{c:}$ Carbohydrate fraction

$X_{A:}$ Ash fraction

# Thermal conductivity

ZERO LEARNING ACADEMY
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- 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 ($\Delta T$) 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
- Xp: 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

$$\alpha = K/dC_p$$

where $\alpha$ is the thermal diffusivity, $K$ 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.

# Numericals

**Problem 1.**

**Suppose 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$^o$C**
- = 0.8726 kCal/kg$^o$C

- **$C_p = 4.180\ X_w + 1.711\ X_p + 1.98\ X_f + 1.547\ X_c + 0.908\ X_a$**

**Cp = 4.180*0.07 + 1.711*0.2 + 1.98*0.1 + 1.547*0.6 +0.908*0.015**

Cp = 2.4946 kj/kg c

Cp = 0.2926+0.3422+0.198+0.9282+0.01362

cp = 1.7746 kj/kg c

1 kcal = 4.18 kj

**Cp = 0.424 kcal/kg c**

# Contd….

- **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$^0$C.**
- **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

# Contd…

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- **Example 11.3**

  **Compute the temperature at which ice formation begins in an ice cream mix with the following composition: 10% butter fat, 12% solids-not-fat, 15% sucrose and 0.22% stabilizer.**

- The solute accounted for in the ice-cream mix is sucrose (W = 342) and lactose (W = 342), which represents 54.5 % of the SNF in the mix. – Molality is computed as:
- Fraction solute = 0.15 + 0.545(0.12) = 0.2154 g/ g product
- When expressed in terms of water fraction (62.78%), thus 0.2154/0.6278 = 0.3431 g solute/g solvent or 343.1 g solute / 1000g solvent
- And m = 343.1/342 = 1.003
- Therefore initial ice formation will occur at (273-1.86) 271.14 K or -1.86$^{o}$C